Improving DXA Quality by Avoiding Common Technical and Diagnostic Pitfalls: Part 1

Kevin P. Banks[1,2], Mary Beth Farrell[3], Rutger S. Gunther[1], Nathan E. McWhorter[1,2], Doug W. Byerly[1,2], and Justin G. Peacock[1,2]

[1]Department of Radiology, Brooke Army Medical Center, San Antonio, Texas; [2]Department of Radiology, Uniformed Services University, Bethesda, Maryland; and [3]Intersocietal Accreditation Commission, Ellicott City, Maryland

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Dual-energy x-ray absorptiometry (DXA) is an accurate means to assess bone mineral density, determine the risk of a fragility fracture, and monitor response to therapy. Despite its seemingly straightforward nature—the review of 2-to-3 nondiagnostic images and a few automatically generated numbers—the proper performance and interpretation of DXA can often be complex. It is complex because it is highly dependent on many factors, such as image acquisition, processing, analysis, and subsequent examination interpretation. Each step is subject to potential errors, artifacts, and diagnostic pitfalls; hence, meticulous attention must be paid to the technique by both the technologist and the interpreting physician to provide high-quality results and, in turn, maximize the examination's clinical utility. This article is part 1 of a 2-part series. Part 1 will begin with a review of bone physiology and osteoporosis etiology, followed by a discussion of the principles underlying DXA and the technical procedure. Part 2 will focus on DXA interpretation and discuss scanning pitfalls and clues to recognizing issues and improving scan quality.

Key Words: dual-energy x-ray absorptiometry; DXA; DEXA; bone mineral density; osteoporosis; osteopenia

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Osteoporosis is a skeletal disorder of weakened bone strength resulting in elevated fracture risk. A common but silent disease until a fracture occurs, an estimated one half of women and one fifth of men over age 50 y will experience an osteoporosis-related fracture (*1*). These fractures are referred to as fragility fractures because they result from low-energy trauma, equal to or less than a fall from standing height. The most common fracture sites are the spine, pelvis, hip, and distal radius. These fractures commonly result in long-term disability, diminished quality of life, and increased mortality, particularly with hip fractures, which almost always require hospitalization and have a 20% mortality rate and 50% permanent disability rate (*2*). With one-third of people in the United States aged 50 y or older, the prevention, detection, and treatment of this prevalent disease are critical to the well-being of a substantial portion of the population (*3*).

Bone strength and, consequently, fracture risk are a function of bone quality and bone mineral density (BMD). Bone quality comprises approximately 30% of bone strength, whereas BMD comprises the remaining 70%. Bone quality refers to a constellation of factors influencing how well a bone resists fracturing. These factors include osseous architecture, accumulated microscopic damage, mineral crystal size, collagen structure, and bone turnover rate (*4*). BMD is simply the bone mass per area (g/cm^2) (*5*).

Bone quality cannot be directly measured in the clinical setting. Bone density, however, can easily be measured via dual-energy x-ray absorptiometry (DXA), a quick, inexpensive, and readily available radiologic procedure. This article is part 1 of a 2-part series. Part 1 will begin with a review of bone physiology and osteoporosis etiology, followed by a discussion of the principles underlying DXA and the technical procedure. Part 2 will focus on DXA interpretation and discuss scanning pitfalls and clues to recognizing issues and improving scan quality.

BONE PHYSIOLOGY AND OSTEOPOROSIS

Bone Physiology

Normal bone physiology is a process of formation and remodeling (*6*). Bones grow in both the longitudinal and the radial directions, with continuous remodeling throughout life in reaction to microtrauma. It is estimated that most of an adult's skeleton is replaced every 10 y. Bone remodeling is essential because it replenishes bone strength and mineral content, thus averting the accumulation of damaged bone.

There are 2 types of bone: cortical and trabecular. Cortical bone, also known as compact bone, is the hard outer layer of

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For correspondence or reprints, contact Mary Beth Farrell (farrell@intersocietal.org).
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strong, dense bone. Trabecular bone, also called cancellous bone, is the lighter, less dense, spongy inner network of trabeculae (meshlike layer of holes connected by thin rods and plates filled with red bone marrow) (*7*). Approximately 3% of cortical bone is resorbed and replaced each year, compared with 25% of trabecular bone.

Although cortical bone and trabecular bone differ in their structure, they have a similar molecular composition (*6*). Both have an extracellular matrix, and the composition and arrangement of the extracellular matrix determine a bone's mechanical characteristics. Bone strength is influenced by collagenous proteins (tensile strength) and mineralized osteoid (compressive strength).

Bone Cells. Three predominant bone cells include osteocytes, osteoclasts, and osteoblasts. Osteocytes account for 90%–95% of total bone cells (*8*). The adult body has approximately 42 billion. They have a lifespan of up to 25 y. They are often described as terminally differentiated osteoblasts embedded in a mineralized osteoid matrix of calcium and phosphate (hydroxyapatite).

Osteoclasts are responsible for bone resorption, whereas osteoblasts are responsible for bone formation. Their function depends on each other and is linked in regard to bone remodeling. For resorption, osteoclasts secret acid and enzymes that digest bone minerals and bone matrix. Osteoblasts secrete and mineralize osteoid bone and control osteoclast resorption. Osteoblasts differentiated into osteocytes appear to control the timing and location of remodeling in response to environmental stress or mechanical strain. Osteoclast resorption of bone, at the microscopic scale, takes weeks, whereas osteoblast formation of new bone takes 4–6 mo. Thus, any condition that increases the rate of bone remodeling causes net bone loss over time.

Bone Remodeling Phases. Peak bone mass, representing the greatest amount of bone a person can reach or the bony tissue present at the end of skeletal maturation, occurs between 20 and 30 y of age for men and women, with men typically reaching a higher peak (Fig. 1) (*6*). In men, bone mass gradually declines over time until old age. In women, bone mass plateaus until menopause, and then there is an accelerated period of bone loss for several years. After peak bone mass is attained, bone mass and structural integrity are determined by remodeling for the remainder of a person's life.

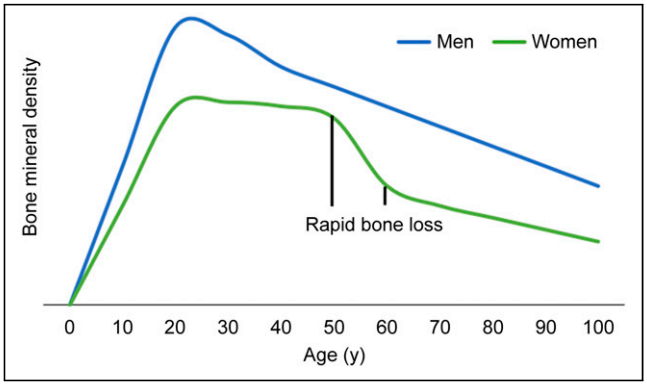

FIGURE 1. Normal bone loss over time for men and women. For both men and women, bone mass peaks at 20–30 y old. Men then begin to lose bone mass over time gradually. Bone mass in women plateaus until menopause, and then there is rapid bone loss for several years.

During remodeling, old bone tissue is replaced by new bone tissue through coupling of bone formation and resorption. There are 4 sequential phases: quiescence/activation, resorption, reversal, and formation. During quiescence/activation, cytokines and growth factors stimulate preosteoclasts, which differentiate into mature osteoclasts, which digest old bone during the resorption phase. During reversal, the resorption of the mineral matrix ends, and the osteoclasts signal preosteoblasts to initiate bone formation. During the bone formation phase, osteoblasts synthesize new bone by producing an organic matrix of protein and polysaccharides (osteoid) that become bone after mineralization. At the end of formation, the osteoblasts become quiescent and line the newly formed bone surface.

Osteoporosis

Osteoporosis Etiology. Osteoporosis is defined as low bone mass and microstructural weakening of bone tissue leading to increased bone fragility (*6*). The reduction in bone mass is caused by a decoupling of bone resorption and bone formation. Normally, bone resorption and formation are fairly equally balanced. However, a decrease in bone formation or an increase in bone resorption can result in osteoporosis. In osteoporosis, the coupling mechanism between osteoclasts and osteoblasts does not keep pace with the continuous microtrauma of the trabecular bone. The cause of the imbalance is multifactorial based on genetic, intrinsic, exogenous, and lifestyle factors.

Osteoporosis can be categorized as primary or secondary (Fig. 2). Primary, or idiopathic, osteoporosis, the most common type, can be further divided into postmenopausal (type I) and age-associated or senile (type II) osteoporosis. A decrease in estrogen is the main cause of postmenopausal osteoporosis. Senile osteoporosis is caused by decreased calcium and an aging skeleton. Secondary osteoporosis is caused by disease processes (e.g., renal hypercalciuria or Cushing syndrome), dietary deficiency (e.g., alcoholism or anorexia), or medications (e.g., glucocorticoid, proton pump inhibitors, or selective serotonin reuptake inhibitors).

The primary risk factor for osteoporosis is advanced age. However, there are many other identified risk factors, such as being female, having white or Asian ethnicity, or having a family history of osteoporosis (Table 1).

Osteoporosis Treatment. Although there is no cure for osteoporosis, the prognosis is good if it is detected early and properly treated. Thus, prevention and recognition of the causes are the primary steps to lessen the impact and halt progression of the disease (*6*). Treatment includes lifestyle modifications such as increased exercise, smoking cessation, and limiting of alcohol consumption. Calcium and vitamin D are also usually prescribed.

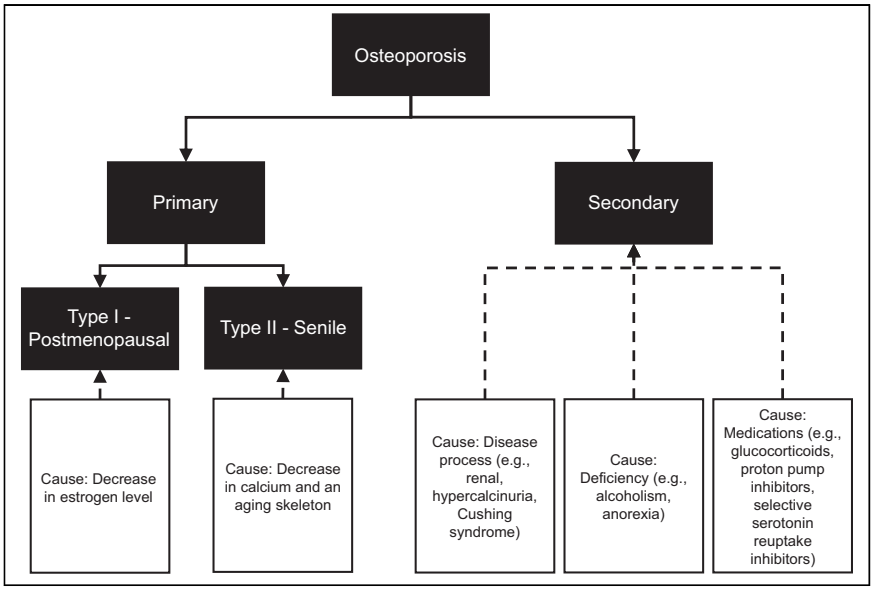

FIGURE 2. Osteoporosis types. Osteoporosis can be categorized as primary or secondary. Primary osteoporosis consists of type 1 (postmenopausal) and type II (also called senile). Type I is caused by decreases in estrogen levels, whereas type II is caused by decreased calcium and skeletal aging. Secondary osteoporosis is caused by other diseases, diet, or medications.

Some medications may be helpful, depending on the underlying cause of osteoporosis (Table 2). These include antiresorptive agents such as bisphosphonates (e.g., alendronate [Fosamax; Merck], risedronate [Actonel; Allergan Pharma], or zoledronic acid [ReClast; Novartis]), which reduce osteoclast function; selective estrogen receptor modulators (e.g., raloxifene [Evista; Eli Lilly] and bazedoxifene [Duavee, Duavive, Pfizer, Inc.]), which act on estrogen receptors to downmodulate osteoclast activity; RANK (receptor activator of nuclear factor κ B) ligand inhibitors such as denosumab (e.g., Prolia [Amgen] and Xgeva [Amgen]), which block osteoclast maturation; and anabolic agents (e.g., abaloparatide (Tymlos [Radius Health, Inc.]) and teriparatide (Forteo [Eli Lilly]), which promote new bone formation (*9–12*).

TABLE 1
Osteoporosis Risk Factors

Category	Risk factor
Nonmodifiable	≥50 y old
	Female
	Asian or white ethnicity
	Family history
	Thin physique or low weight (<57.6 kg [127 lb])
	Androgen or estrogen deficiency
	Hypogonadism
	Amenorrhea
	Late menarche
	Early menopause
	Postmenopausal
	Immobility
	Certain medications (e.g., anticonvulsants, steroids, thyroid drugs, heparin, chemotherapy, insulin)
	Dowager hump (focal kyphosis of upper thoracic spine)
Modifiable	Physical inactivity
	Smoking
	Excessive alcohol consumption
	Low calcium or vitamin D

DXA PRINCIPLES

Newer nuclear medicine technologists may not realize that DXA began as a nuclear medicine procedure, and DXA is still performed in many nuclear medicine departments today. The systems used in the 1970s to measure BMD were dual-energy photon absorptiometry systems that measured the attenuation of monochromatic emissions from the radioisotope ^{153}Gd (*13*). In 1987, the first DXA scanners became commercially available. DXA uses polychromatic x-ray spectra at different energy levels. Using x-rays shortened the examination time because of the higher photon flux from the x-ray tube, resulting in better resolution and precision.

DXA is based on the variable absorption of x-ray photons by different tissues in the body. An x-ray source below the patient produces alternating high-energy (140 kVp) and low-energy (70–100 kVp) pulses. The use of 2 distinct energy levels enables bone to be measured separately from soft tissue (*14*). A detector above the patient measures the transmitted low- and high-energy photons and calculates bone density based on the difference between soft-tissue and bone attenuation. Although density typically represents mass per unit volume, DXA results are obtained from a planar (2-dimensional) image, and consequently, depth cannot be determined (*13*). Therefore, density, or more accurately areal density, is reported as mass per unit area (g/cm^2), unlike CT, for which traditional density is reported as mass per volume (g/cm^3).

The calculated BMD results are compared with a reference-subject database. The SD (how much the result varies from the average mean) is reported as a T-score or a Z-score. The scores indicate the relationship between peak bone mass and subsequent bone loss. The results may vary somewhat between manufacturers depending on the database used and differences in the technology.

The T-score, as defined by the World Health Organization, represents how a patient's measured BMD differs from that of a healthy 30-y-old adult woman (presumed peak bone mass) (*15*). The T-score is used to assess BMD

TABLE 2
Osteoporosis Medications

Type	Function	Example
Antiresorptive agents	Reduce osteoclast function	Bisphosphonates: alendronate, risedronate, zoledronic acid
Selective estrogen receptor modulators	Act on estrogen receptors to downmodulate osteoclast activity	Raloxifene, bazedoxifene (FRAX)
RANK ligand inhibitors	Block osteoclast maturation	Denosumab
Anabolic agents	Promote new bone formation	Abaloparatide teriparatide

in postmenopausal women and men aged 50 y and older. In contrast, younger patients, particularly children, are assessed using a Z-score, which also considers age, sex, and ethnicity.

The T-score, not to be confused with the "t" in the commonly used Student *t* test, is determined by taking the difference between the patient's measured BMD and the mean BMD of healthy 30-y-old adults, which is then divided by the 30-y-old adult SD (*16*).

$$\text{T-score} = \frac{\text{patient BMD} - \text{mean healthy 30-y-old adult BMD}}{\text{healthy 30-y-old adult SD}}$$

A T-score of −1.0 (SD) or greater is considered normal BMD, and a T-score of −2.5 or less is diagnostic of osteoporosis (*15*). T-scores of less than −1.0 but greater than −2.5 are classified as osteopenia, with *low bone density* also an acceptable term (Table 3).

Z-scores are calculated similarly to T-scores; however, Z-scores use the mean age-, sex-, and ethnicity-matched (population-specific) score.

$$\text{Z-score} = \frac{\text{patient BMD} - \text{mean population-specific (matched) BMD}}{\text{population-specific SD}}$$

Z-scores of greater than −2.0 are considered normal, whereas scores of −2.0 or less are considered low bone density for age. Note, Z-scores are not used to formally diagnose osteoporosis; instead, the score serves as a clue to look for a cause of secondary osteoporosis.

TABLE 3
World Health Organization Osteoporosis T-Score Classification*

T-score	Classification
≥−1	Normal
Between −1.0 and −2.5	Osteopenia
≤−2.5 or lower	Osteoporosis
≤−2.5 (with fragility fracture)	Severe or established osteoporosis

*Compared with mean bone density of young adult women.

DXA ALTERNATIVES

DXA is the preferred technique to measure BMD because of its high precision and accuracy (1%–2% margin of error) (*17*). Precision refers to the reproducibility of a measurement, whereas accuracy refers to how close a measurement is to the true value. DXA measurements also can be quickly obtained at a relatively low radiation dose. However, other methods are available, including quantitative CT (QCT) and quantitative ultrasound (QUS).

QCT of the lumbar spine, or central QCT, is performed on a standard CT machine using specialized protocols. QCT of the forearm, also called peripheral QCT, can be measured using smaller, less sophisticated equipment; however, the measurements correlate poorly with central measures (*16*). QCT is a 3-dimensional technique that calculates the true volume and volumetric bone density (g/cm^3) (*13*). The geometry of the vertebra can be assessed. QCT also allows for differentiation between cortical and trabecular bone (*18*). However, one drawback to QCT is the higher radiation dose than DXA. Another drawback is the lack of validated diagnostic criteria.

QUS can assess the BMD of the peripheral skeleton, usually the calcaneus. QUS uses ultrasound attenuation instead of x-ray attenuation and the speed of sound. The advantages of QUS are that it is relatively inexpensive compared with QCT and DXA and that the equipment can be portable. The disadvantage of QUS is that it is less accurate than QCT and DXA.

DXA PROCEDURE

Indications/Contraindications

The practice parameters of the American College of Radiology, Society for Pediatric Radiology, and Society for Skeletal Radiology provide a long list of clinical indications for DXA (*23*). Essentially, DXA is used to diagnose abnormalities of BMD, estimate the risk of fractures, monitor changes in density over time, and assess response to treatment.

There are no absolute contraindications for DXA (*14*). However, several conditions may result in scans of limited value: recent administration of gastrointestinal contrast media or radiopharmaceuticals, severe degenerative changes in the measurement area, fracture, implants or devices in the measurement area, patient's inability to be positioned or remain motionless during the scan, and extremely low or high body mass. Pregnancy is a relative contraindication, and the risks

TABLE 4
Patient Medical History Screening

Category	Condition
Bone marrow disorders	Multiple myeloma
	Myelodysplasia
	Systemic mastocytosis
	Thalassemia
Endocrine or metabolic diseases	Acromegaly
	Anorexia nervosa
	Cushing syndrome
	Diabetes mellitus type 1
	Hypercalcemia
	Hyperparathyroidism
	Hyperprolactinemia
	Hyperthyroidism
	Hypopituitarism
Other conditions	Chronic kidney disease
	History of organ transplantation
	Hypercalciuria
	Immobilization (e.g., paraplegia, quadriplegia, or muscular dystrophy)
	Inadequate calcium uptake
	Malabsorption (e.g., celiac disease)
	Rheumatoid arthritis
	Secondary hyperparathyroidism due to renal disease
	Vitamin D deficiency

TABLE 5
Medications Causing Bone Loss or Increased Fracture Risk

Parameter	Medication
Bone loss	Anticonvulsants (e.g., phenobarbital, phenytoin)
	Aromatase inhibitors
	Cytotoxic agents
	Glucocorticoids > 3 mo
	Gonadotropin-releasing hormone agonists or antagonists (e.g., androgen deprivation therapy, Lupron [AbbVie])
	Immunosuppressive agents (e.g., cyclosporine)
	Intramuscular medroxyprogesterone (Depo-Provera [AbbVie])
	Thyroid hormone excess
Increased fracture risk	Benzodiazepines/Z-drugs, insulin with hypoglycemia, opioids, thiazolidinediones, selective norepinephrine reuptake inhibitors, selective serotonin reuptake inhibitors, SGLT-2 inhibitors

Z-drugs = eszopiclone (Lunesta; Sunovion Medical); zaleplon (Sonata; Pfizer); and zolpidem (Ambien; Sanofi-Aventis LLC); SGLT-2 = sodium-glucose co-transporter 2.

and benefits of DXA should be discussed with the referring physician.

Patient Preparation

Patients should be prescreened to ensure that they can lie on their back for up to 10 min. They should have received no barium or gadolinium oral contrast medium within 2 wk beforehand, and they should have taken no calcium tablets within 24 h before the scan (*18*). They should be wearing loose-fitting clothing without metal. Finally, if they underwent DXA previously, they should have brought a copy of the results for comparison.

A detailed patient history is required to perform and interpret DXA correctly. The history should include risk factors, prior surgery that could affect the accuracy of measurements, previous fractures, endocrine or metabolic diseases, bone marrow–related disorders, and other associated conditions (Table 4) (*19*). Patients should also be screened for medications associated with bone loss or increased fracture risk (Table 5). The International Society of Clinical Densitometry (www.iscd.org) provides patient history questionnaires.

In addition, the World Health Organization fracture risk algorithm can be used to calculate a score from the patient history that can be used to correlate with DXA findings. The FRAX estimates the 10-y probability of fracture due to osteoporosis in postmenopausal women and men over 50 y old. It evaluates risk factors including age, sex, low body weight, height, previous fracture, parent history of hip fracture, smoking, glucocorticoid use, history of rheumatoid arthritis, menopausal state, and excess alcohol intake (*19*). The FRAX tool is helpful for risk-stratifying osteopenic individuals to identify those who are most likely to benefit from therapy.

Acquisition

Equipment. Several manufacturers produce DXA scanners, and the equipment can be full-table systems that can measure multiple sites, such as the spine or hip, or peripheral systems that measure the wrist or ankle (*20*). Full-table systems offer the most options and are the preferred osteoporosis assessment and management method.

The first-generation DXA scanners used pencil-beam geometry and a single detector that scanned across the area of interest in a raster pattern (*21*). Current scanners use fan-beam technology with multiple detectors that sweep the measurement area. One advantage of fan-beam over pencil-beam technology is shorter scan times of 30 s for the hip and spine compared with 3–10 min for pencil-beam technology (*13*). The disadvantages of fan-beam scanners include slight image distortion due to magnification of the tissue and increased scanner cost. Another disadvantage of fan-beam scanners is increased scatter.

Quality Control. The accuracy of BMD measurement depends on the consistency of the scanner (*22*). Quality control procedures vary by manufacturer but usually require scanning a dedicated phantom and automatic analysis that checks and calibrates mechanical function, radiation quality, and the absorption coefficient of tissue-equivalent materials. The procedure is performed daily before use and at least

3 times a week (*13*). If the results fall outside the acceptable limits, the scanner should be evaluated by a field service engineer.

Cross-calibration procedures are necessary for precise longitudinal assessment when replacing scanners (the same model is usually preferred) or validating measurements between systems (*22*). Cross calibration entails scanning the phantom 10 times on each scanner. The measures should be within 1%.

Areas of Study. For routine DXA, the lumbar spine and hip are assessed, with measurement of either or both hips considered acceptable. Assessment of both hips provides information on the hip with the lowest BMD and allows for longitudinal evaluation even if one hip is fractured or undergoes surgery in the future (*23*). In addition, the nondominant forearm BMD should be included in all patients with hyperparathyroidism. The forearm should also be measured when the hip or spine cannot be measured or correctly interpreted because of hardware or other confounding factors. The final diagnosis is made using the lowest score among the measured skeletal sites.

The patient must remove all objects from their pockets or body in the scan field, such as wallets, cell phones, underwire bras, watches, and bracelets.

Positioning. Correct patient positioning is essential to obtaining reliable and reproducible BMD measurements. Incorrect positioning is one of the most common reasons for errors.

Spine. For the spine, posteroanterior images are obtained of L1–L4 with the patient lying supine on the DXA table (*24*). The lower back should be aligned in the middle of the table with the spine straight compared with the table's long axis and not rotated (Fig. 3). A tip to ensure that the spine is straight is to stand at the patient's head, gently reach under the underarms, and pull the patient upward. The legs should be elevated using a foam block—placed under the patient's lower legs so the thighs are as close to a 90° angle to the body as possible—to minimize lordosis and increase intervertebral spacing. The patient should rest the arms and hands comfortably at the sides.

The scan field of view extends superiorly to include a portion of the lowest thoracic vertebra (confirmed by the presence of ribs) and inferiorly to show the iliac crests (about the level of the L4–L5 interspace). Usually, proper patient positioning can be achieved by locating the patient's iliac crest and starting the scan 5 cm (2 in) below. Most scanners begin the acquisition inferiorly and move superiorly.

As the scan is acquired, the technologist monitors the emerging planar image to ensure that the entire spine is centered and straight. There should be equal amounts of soft tissue on both sides of the spine, and a small part of the iliac crest should be visible in the lower corners of the screen. If the patient is not positioned correctly, the technologist should stop the scan, reposition, and restart the acquisition. The scan can be terminated when the ribs attached to the 12th thoracic vertebra (T12) are visualized.

Hip. The hip images must include the entire femoral head, the greater trochanter, and 2.5 cm (1 in) or more of the femoral shaft below the lesser trochanter (Fig. 4). The technologist must first locate the patient's greater trochanter to ensure that the hip is correctly positioned in the field of view. The greater trochanter can be identified by holding the patient's ankle and rotating inward and outward while pressing firmly on the thigh with the other hand. The greater trochanter will roll back and forth under the fingertips. An alternative method is to ask the patient to bend at the knee and lift the leg. The crease formed at the top of the leg is approximately in line with the greater trochanter.

A hip-positioning device is placed under the patient's lower legs at the midline of the patient's body. The long axis of the femur should be parallel to the long axis of the table.

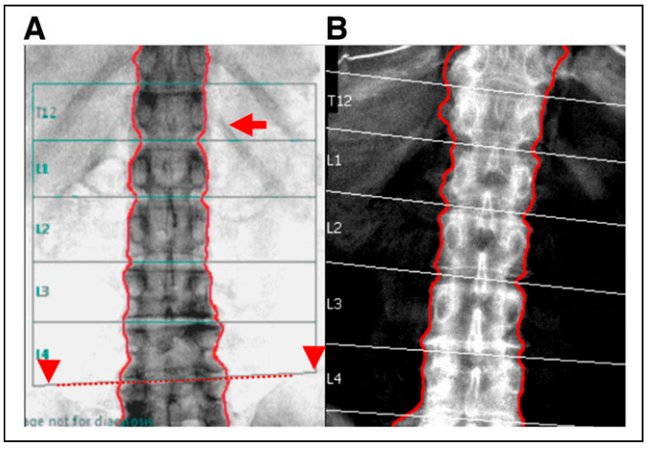

FIGURE 3. (A) Properly positioned posteroanterior view of lumbar spine with appropriate field of view. Spinous processes should be centered straight (midline) and include part of iliac crest (arrowheads) and part of vertebra with ribs (arrow). Iliac crests provide helpful landmark. Dashed line connecting this will typically bisect L4–5 disk space. (B) Incorrectly positioned posteroanterior view of lumbar spine in which spine is angled and left iliac crest is not visible.

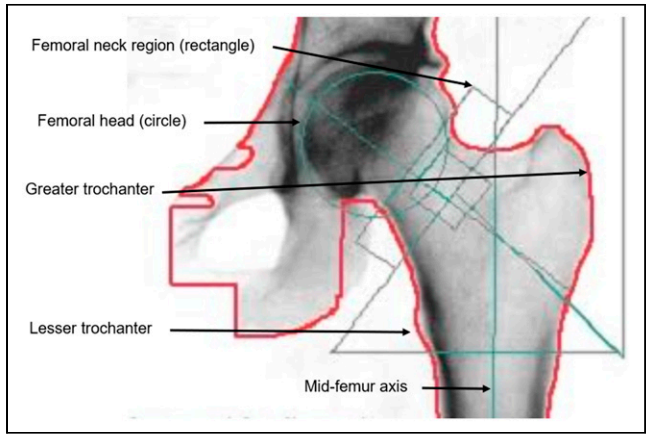

FIGURE 4. Essential hip anatomy for proper positioning includes femoral head, femoral neck, greater trochanter, lesser trochanter, and mid-femur axis.

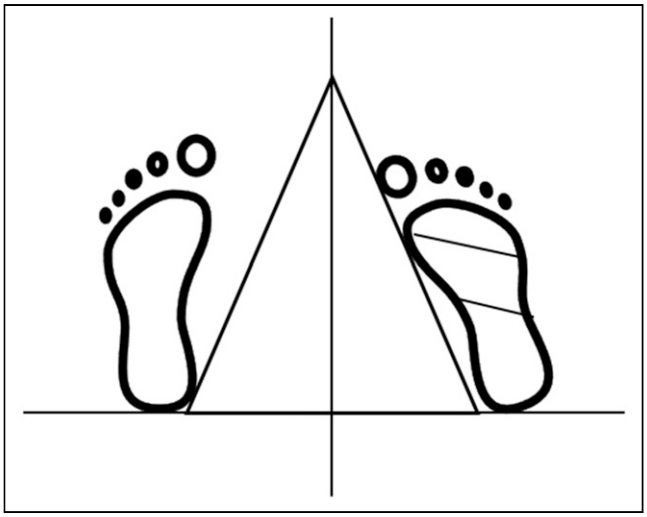

FIGURE 5. Hip positioning device. To properly align axis of femoral neck, leg must be rotated 15°–25° inward and strapped to hip-positioning device.

The leg of the hip to be measured is rotated inward and strapped against the positioning device, abducting or internally rotating 15°–25° to position the femoral neck axis parallel to the table plane and ensure precise measurement (Fig. 5). When rotating the leg, the technologist should place one hand above the knee and the other hand below the knee and gently turn the entire leg, not just the lower portion.

Incorrect leg rotation causes foreshortening of the femoral neck, presenting a smaller cross-sectional area, possibly resulting in a falsely elevated BMD (*25*). An excess of internal or external rotation of as low as 10° can lead to significant changes in measured BMD in approximately 10% of patients (Fig. 6).

The patient can rest the arms on the chest or outside the scan field. The scan begins at a position 5 cm (2 in) below the level of the greater trochanter. A horizontal laser line can ensure that the femoral shaft is parallel.

On scan completion, the technologist should verify correct hip positioning. The lesser trochanter will be barely visible on a properly aligned and rotated hip, and the shaft of the femur will be straight.

Forearm. When the forearm is being imaged, the patient sits next to the table, with the nondominant forearm, wrist, and hand laid flat, palm side down, and secured to a positioning board with a restraining strap (*26*). The ulnar and radial shafts should be aligned with the long axis of the table, with the carpal bones in the top third of the image (Fig. 7). This position ensures inclusion of the radius 33% (also known as one-third radius), consisting of a 20-mm length of the radial shaft located one third of the distance between the ulnar styloid and the olecranon. The radius 33% is the recommended forearm site when either the lumbar spine or the hip cannot be assessed or in cases of hyperparathyroidism.

Analysis

The first step in analyzing the DXA image is to confirm positioning and the absence of patient motion on the planar image (*27*). The image must also be reviewed for artifacts such as metal, overlying hardware, or barium.

Spine. Most DXA scanners use automated region-of-interest (ROI) placement. However, the technologist must manually adjust the ROI to ensure appropriate intervertebral designations (*13*). Correct identification and numbering of the lumbar vertebrae are critical. Staron et al. found that incorrect intervertebral disk space ROI placement was the most common analysis error (*28*).

The spine measurement region includes L1 through L4, with the box placed at the top of L1 and the bottom of L4 (*13*). The intervertebral lines should be moved and angled as appropriate to ensure proper numbering of the vertebrae. A line drawn from the highest point of one iliac crest to the other iliac crest most commonly traverses the L4–L5 intervertebral disk space and is used as a landmark (*29*). In addition, there must be adequate soft tissue on both sides of the spine; insufficient soft tissue results in underestimation of the BMD.

Hip. The hip ROI includes the femoral neck, trochanter, and total hip. Although the Ward triangle (not a true anatomic area but a calculated area of the lowest BMD in the femoral head) and the intertrochanteric region are often

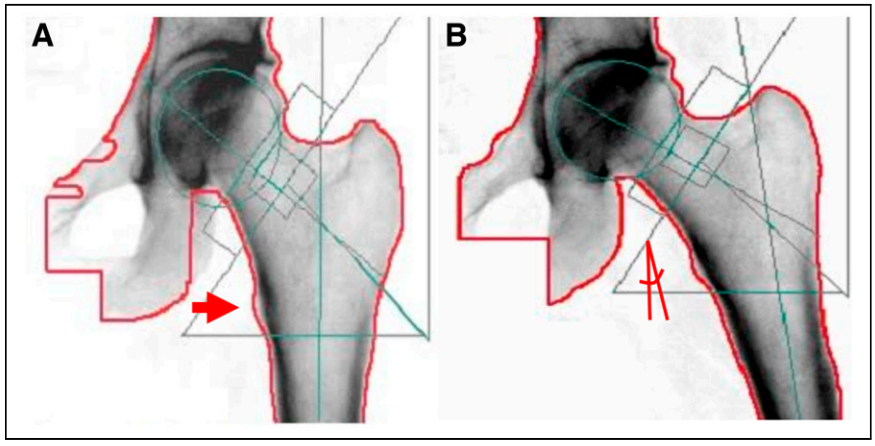

FIGURE 6. (A) Properly positioned hip. Femur shaft is aligned with craniocaudal axis. Appropriate internal rotation is demonstrated by minimal visualization of lesser trochanter (arrow). Field of view is centered correctly with greater trochanter at midway craniocaudal point. (B) Improperly positioned hip with femoral shaft off axis, in 20° of abduction (angle). Incorrect rotation or alignment causes foreshortening of femoral neck, which presents smaller cross-sectional area, possibly resulting in falsely elevated BMD. Excess internal or external rotation of as low as 10° can lead to significant changes in measured BMD in approximately 10% of patients (*25*). Additionally, this incorrect positioning is often not reproduced on follow-up, potentially propagating error by calculation of spurious interval change.

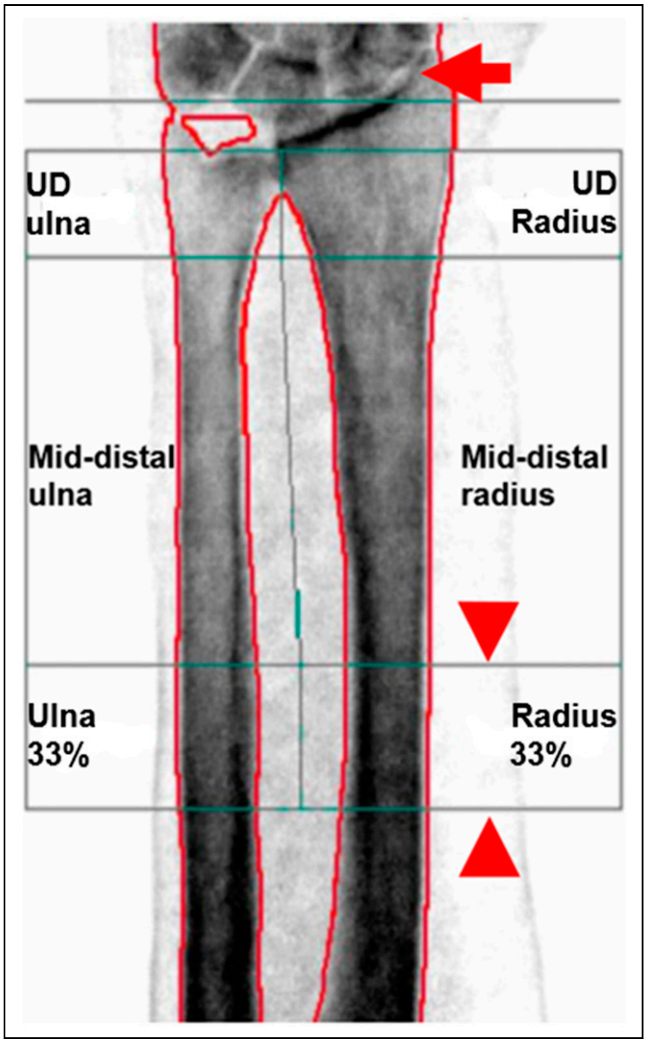

FIGURE 7. Appropriately positioned nondominant forearm. Ulnar and radial shafts are aligned with long axis of table, with carpal bones (arrow) in top third of image. This position ensures inclusion of radius 33%, also known as one-third radius, consisting of 20-mm length of radial shaft located one third of distance between ulnar styloid and olecranon (arrowheads). UD = ultradistal.

included in manufacturers' hip BMD results, these regions are not relevant and not reported (*30*). The first step in the hip analysis is to ensure that the line midline and parallel through the hip is correctly placed. All other ROIs depend on correct placement of this line. The femoral neck ROI is usually placed halfway between the femoral head and trochanter or on the distal portion of the femoral neck, depending on the DXA manufacturer.

Forearm. The ROI for the forearm must be manually positioned. The 3 regions of the distal radius must be defined: the ultradistal region (a 15-mm section from the endplate of the radius); the proximal region, also called the one-third distal (a 20-mm section one third of the distance between the ulnar styloid and the olecranon); and the intermediate or mid-distal radius (the remaining section between the 2 other regions) (*26*).

Longitudinal Measurement Note

Currently available DXA systems use various filters, collimators, detectors, and analysis algorithms (*18*). Thus, it is advisable to perform longitudinal measurements or follow-up scans on the same piece of equipment as earlier scans. When scans are performed on the same stationary equipment, accuracy is high, with a margin of error of 1%–2% (*17*). In addition, the same skeletal site, ROI, and area size should be used if quantitative comparisons are performed (*23*). Only qualitative comparisons can be made if follow-up scans are done on a different device.

Radiation Dose

The radiation dose from DXA is relatively low (*18*). The average dose for spine-plus-hip DXA ranges from 1 to 15 μSv, depending on the equipment (*31*). The dose from pencil-beam systems is usually less, at about 1 μSv, whereas fan-beam systems may be up to 15 μSv. For comparison, the average effective dose from a chest radiograph ranges from 20 to 50 μSv, and the average dose from natural background radiation is about 10 μSv per day. The low radiation doses from DXA make serial imaging acceptable if the initial results are abnormal.

CONCLUSION

Osteoporosis is a common skeletal disorder of weakened bone strength, leading to increased bone fragility and elevated fracture risk. Therefore, preventing, detecting, and treating this disease is critical to the well-being of a substantial portion of the U.S. population. Bone strength and, thus, fracture risk can be assessed from measurement of BMD via DXA.

The precision and accuracy of DXA results depend on the procedure's proper performance and interpretation. Therefore, correct patient positioning, acquisition, and analysis are essential. This article, part 1 of a 2-part series, has laid a foundation for performing DXA by, first, reviewing bone anatomy and physiology along with osteoporosis etiology and treatment. Next, the article explained the principles underlying DXA and the scanner features. Finally, the article detailed the DXA acquisition protocol, including the indications, contraindications, patient preparation, positioning, acquisition, and analysis. Part 2 of the series will review DXA interpretation, use of DXA for monitoring changes in BMD, and pitfalls and clues for quality DXA results.

DISCLOSURE

No potential conflict of interest relevant to this article was reported.

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