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Review Article

Choosing the site to estimate bone mineral density with DXA method

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Abstract

Osteoporosis is a chronic disease requiring prompt and accurate diagnosis. The most widely used quantitative bone imaging technique for estimating Bone Mineral Density (BMD) both for research purposes and in the clinical practice according to WHO, is DXA (dual-energy X-ray absorptiometry). DXA may be performed at the axial (lumbar spine, proximal femur) and appendicular skeleton (distal forearm) for the diagnosis of osteoporosis. In this review, we summarize basic considerations concerning the technique, as well as recommendations for scanning sites in different individuals.

Keywords: Bone Mineral Density, Dual-Energy X-Ray Absorptiometry, Imaging, Osteoporosis

Introduction

Osteoporosis is defined as a systemic metabolic skeletal disease in which bone mass loss and micro-architectural deterioration of bone tissue occurs, leading to a reduction of bone strength and increased risk of fractures. This disease can be classified as primary or secondary due to a variety of causes, and has been shown to represent a major public health problem[1,2].

Diagnosis of osteoporosis focuses on the assessment of bone mineral density (BMD) using dual-energy X-ray absorptiometry (DXA). It is considered to be the "gold standard" method of diagnosis and assesses bone mineral content (grams of hydroxyapatite) per area (cm^2) at pre-specified sites of the axial and appendicular skeleton[1-7]. As a result, the technique provides a two-dimensional image that is affected by the size of the bones, and does not provide a true ("volumetric", mg/cm^3) density, since the relation between area and volume is non-linear[6]. DXA is preferably performed on skeletal sites such as the lumbar spine, proximal femur, and distal forearms, where fracture risk is the highest[1].

The measures provided by DXA are bone mineral content (BMC; in gr), bone area (in cm^2) and areal BMD (in gr/cm^2). To diagnose osteoporosis, the results of areal BMD measurements obtained with DXA, should be reported as the difference in standard deviations (SD's) with the "peak" bone mass, ie the mean mass of young individuals, thus producing a T-score. For females, three general diagnostic categories have been proposed by WHO, for assessments done with DEXA: normal (T-score -1 or above), low bone mass-osteopenia (T-score between -1 and -2.5) and osteoporosis (T-score -2.5 or below)[8]. BMD represents approximately 60-70% of bone strength of isolated bones in vitro and is used as a substitute measure of bone strength in fracture risk prediction[2,4,6].

DXA Technique and Considerations

A. Axial Skeleton DXA

DXA measurements at the lumbar spine and proximal femur are the best substitutes for prediction of future lumbar and hip fracture, respectively, according to the ISCD Official Positions. ISCD and IOF recommend performing DXA both at the lumbar spine and proximal femur for the

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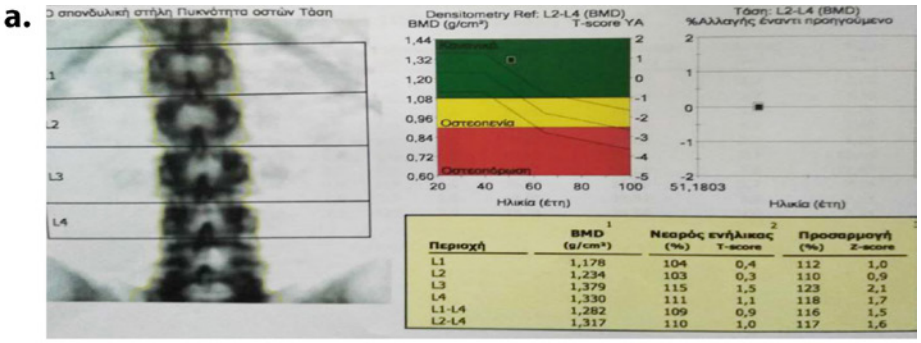

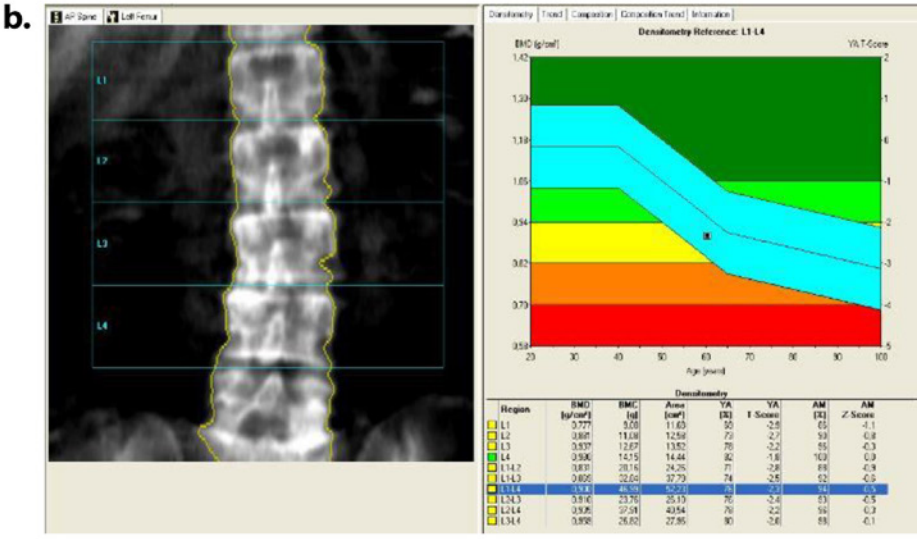

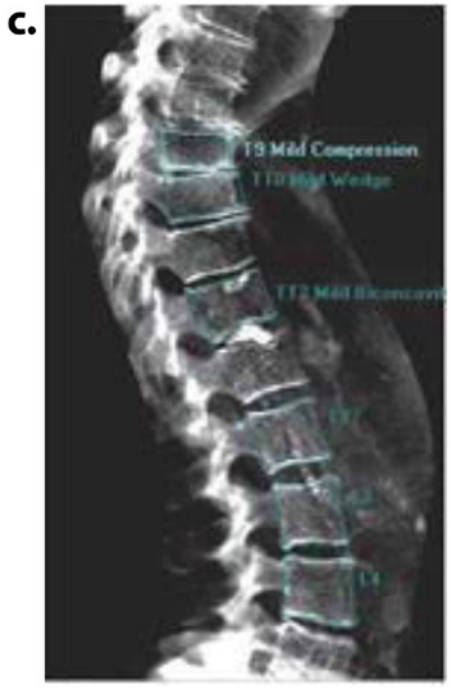

Figure 1. a, b. Appropriate patient's position (DXA image) of lumbar spine that includes T12, ribs, L5. **c.** Lateral DXA as in vertebral morphometry is a very useful tool for the recognition of previous vertebral fractures and not for the diagnosis of osteoporosis (Personal archive of Mr. Sthathopoulos K).

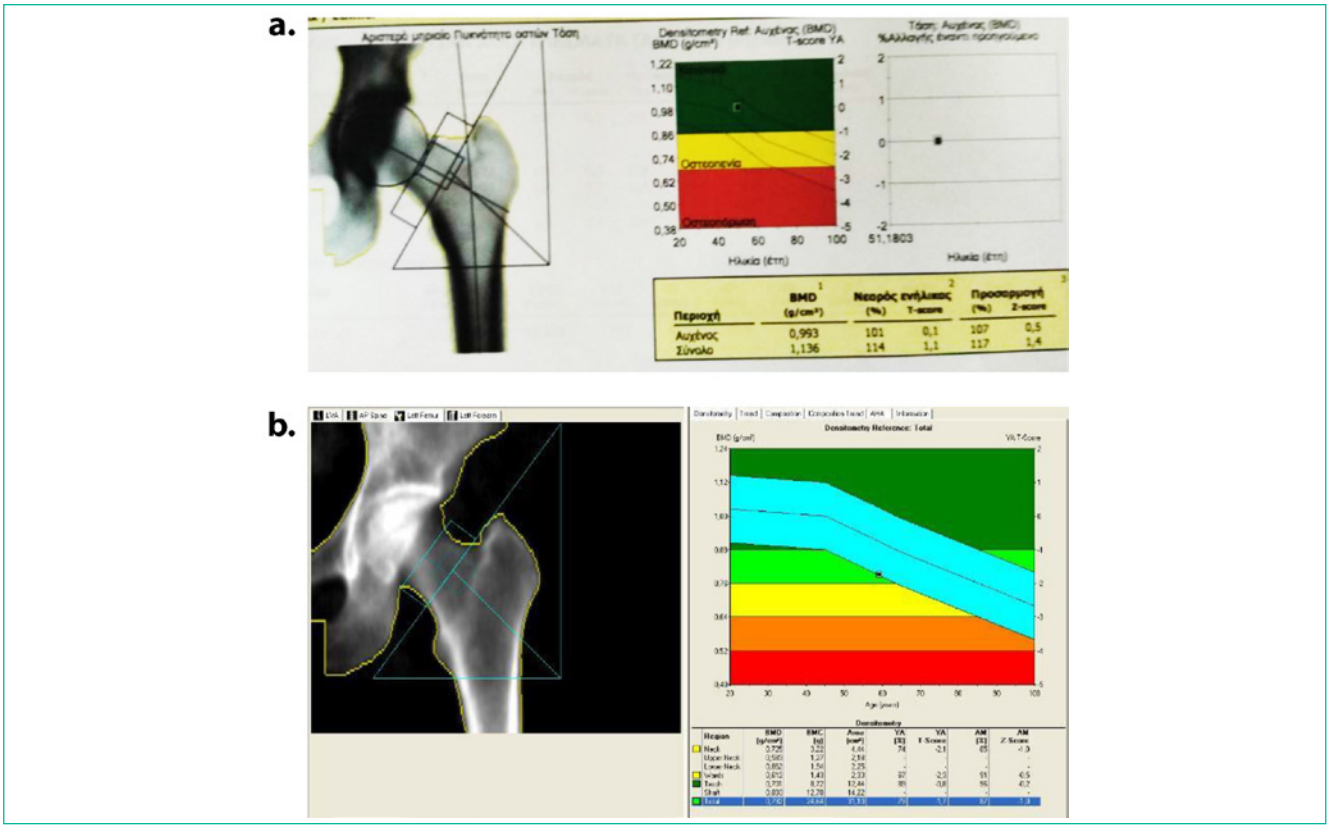

Figure 2. Appropriate ROI position of femur. Green = normal, yellow= osteopenia; red= osteoporosis, BMD= bone mineral density, BMC= bone mineral content.

diagnosis of osteoporosis so that a more thorough approach is undertaken, especially concerning baseline measurements in individuals over the age of 65[7,9,10].

1) Lumbar spine DXA

The preferred Region of Interest (ROI) for the lumbar spine are the first four lumbar vertebrae: POSTERIOR-ANTERIOR (PA) L1-L4. Special considerations are taken into account when one or more vertebrae need to be excluded from the scan, such as vertebral fractures, cement inside the vertebrae due to kyphoplasty/ vertebroplasty or other artifacts. Only the vertebrae that are affected by focal structural abnormalities should be excluded. According to ISCD, up to 2 vertebrae may be excluded from the scan, and if only 2 vertebrae are available, a scan of the hip or forearm is also suggested. BMD measurements based only on one vertebra should not be taking into consideration and diagnosis should be based on another skeletal site[5,8]. According to Hamdy (2002) the specific criteria that will help to decide the exclusion of one or more vertebrae in a densitometry diagnosis of osteoporosis are related to: a) evidence on a DXA image or plain radiography of a focal abnormality, b) large differences of bone area or BMC between adjacent vertebrae (both measures should increase from L1 to L4) and c) T-scores of >1 SD between adjacent vertebrae. In addition, the cause of focal abnormality is advised by referring the patient for additional imaging[5]. The BMD measurement of a lateral spine scan should not be used for the diagnosis of osteoporosis (Figure 1)[5,8].

2) Femur DXA

BMD measurement can be done at either hip according to ISCD. Unlike the forearm, where the BMD is higher in the right forearm in case the individual is right-handed, here does not appear to be a "dominant" hip that would affect BMD measurement[5]. The hip ROIs are the femoral neck, total proximal femur and trochanter, but only the first two are used for the diagnosis of osteoporosis[2,11,12]. Measurement at the hip has the highest and most important predictive value for hip fracture and it predicts the risk of all fractures as well as other techniques[6].

Under normal conditions, no expected significant differences in terms of BMD or T-score of the femoral neck and total hip between the two sides, so either of them may be measured provided that are unaffected by artifacts of prior

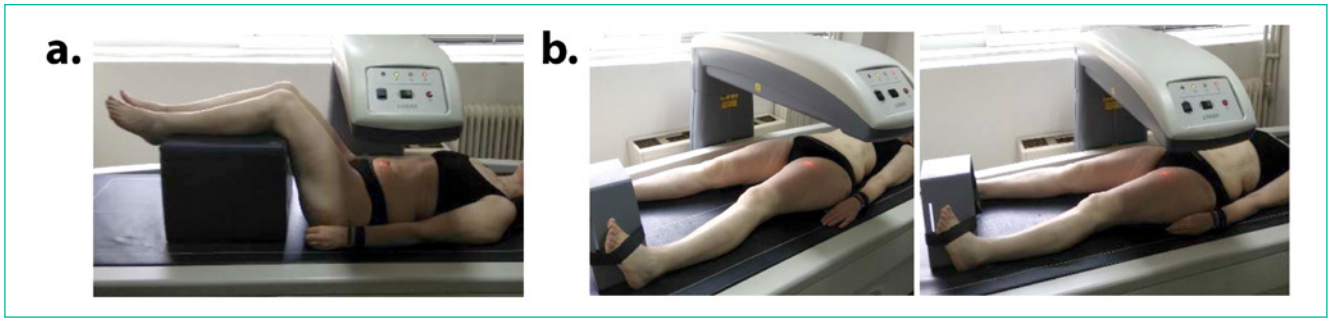

Figure 3. Patient placement for DXA image. **a.** Correct placement of legs for lumbar spine measurement with DXA: supine with hips and knees flexed over support to reduce lordosis. **b.** Correct placement of legs for proximal femur measurement with DXA: supine with lower extremity internally rotated 15°-30° and slightly abducted to keep femoral axis straight.

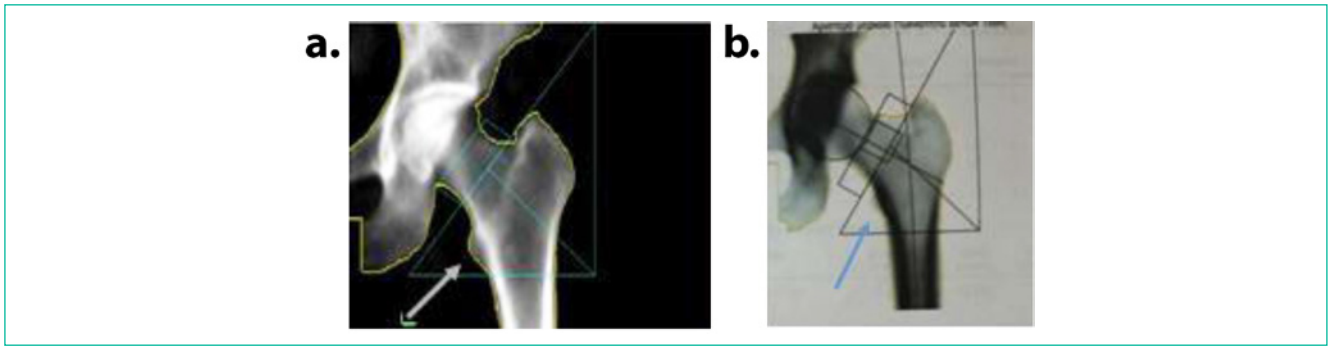

Figure 4. Inappropriate ROI position. **a.** Incorrect placement of femoral head. **b.** Correct rotation in that lesser trochanter is not depicted (arrow).

surgery or any degenerative disease[5,10]. It is considered not to include Ward's area ROI in the report of a diagnosis of osteoporosis as it accounts for a small amount of bone, something that makes it responsible for poor accuracy or reproducibility of measurement and it also decreases the uniformity in densitometry diagnosis. In addition, basing a diagnosis of osteoporosis on the T-score at Ward's area would thus lead to overestimation of lifetime fracture risk (Figure 2)[5].

Appropriate Patient Positioning

To achieve a better evaluation of the diagnosis of osteoporosis with BMD measurement it is important for the patient to be positioned in the right way. When lumbar spine and femoral neck are being measured the patient should be placed in a supine position and sitting next to the table when it comes for imaging of the forearm[11]. In proximal femur scans, it is required the patient to be placed with the foot internally rotated for femoral neck to be parallel to the table and the lesser trochanter to be hidden as much as possible. Poor patient positioning may lead to under- or over-estimation of BMD (Figure 3)[7].

Inappropriate patient positioning

Inappropriate patient positioning is a common phenomenon and leads to false BMD measurements. Longitudinal in vivo precision reflects variability due to positioning: spine, 1.1%; femoral neck, 1.2%; trochanter 1.3% (Figure 4)[11].

Artifacts

In some cases, there may be artifacts in the measurements that should not take part in the image assessment. These objects may include objects with high level of density (surgical materials, catheters, piercings), myelographic agents, vertebroplasty cement, retained contrast medium (barium) and calcifications superimposed on the ROI that increase BMD (dermatomyositis, bone grafts) (Figure 5)[11].

Image Assessment

According to Ramos et al. (2011), in order to be verified that the complete anatomic region is scanned, the area of interest exceeding 1-2 cm and superior and inferior limits should be included. The bone axis should be centered and

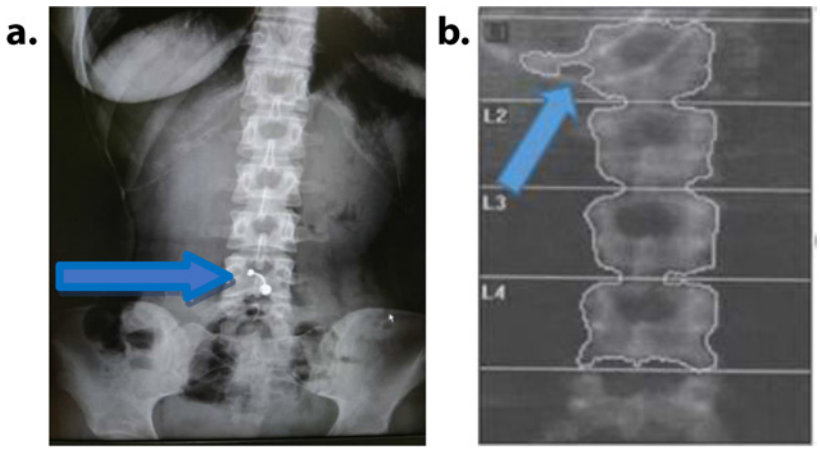

Figure 5. Artifacts caused by dense objects. **a.** Metallic piercing not being removed. **b.** Patient with enteric tube.

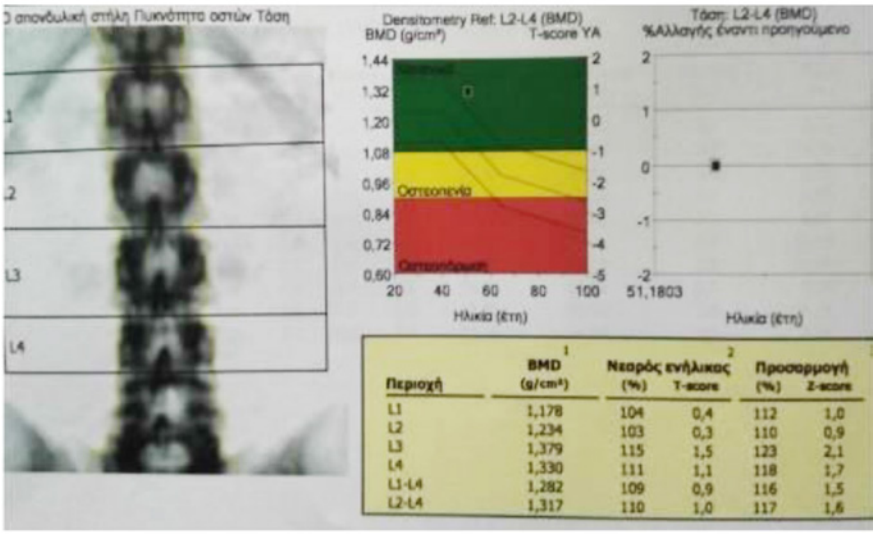

Figure 6. Region of interest (ROI) and image assessment. DXA image of lumbar spine includes T12 and ribs, L5 and iliac bone, and straight and centered spine.

straight. Last but not least, on images of the proximal femur the lesser trochanter should not be seen (Figure 6).

B. Peripheral skeleton DXA

Forearm

A forearm DXA scan can be obtained in three conditions according to ISCD recommendations: when hip or spine cannot be measured accurately or the data of their measurement cannot be interpreted (when patient is exposed to multiple compression fractures and replacements from previous surgery or due to abnormalities), when patient suffers from severe scoliosis, obesity (when the weight exceeds the limit of the densitometer) and in case of hyperparathyroidism. Primary hyperparathyroidism decreases BMD since it affects predominantly cortical more than trabecular bones; the mid-forearm region contains mostly cortical bone and is well suited for this purpose[2,5,11].

The site of forearm that is used for diagnosis is called one-third radius or "33% radius". The ISCD does not recommend the use of all other regions of forearm. In addition, in this case, the non-dominant forearm should also be scanned as the level of BMD in the dominant is higher. For example, in

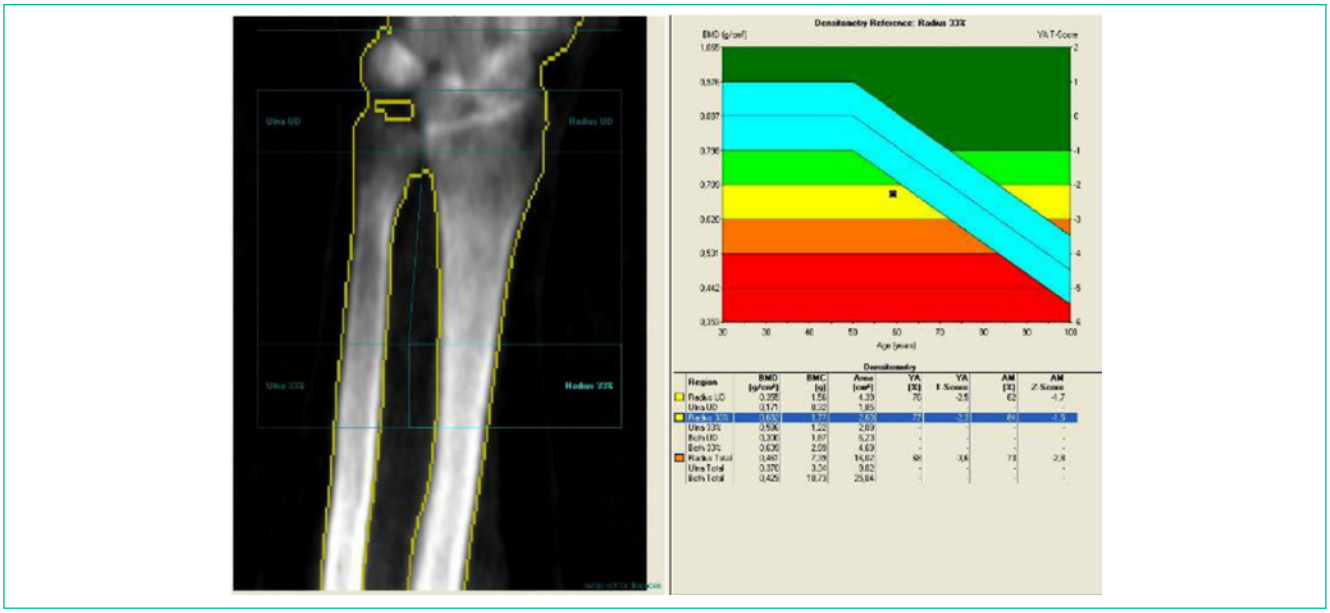

Figure 7. DXA image of forearm. Most important ROI is one-third (1/3) radius. Image should include 2 cm of diaphysis over one third of forearm and part of carpal bones.

right-handed individuals that have higher BMD in the right forearm, it should be used the left one so it will not affect the BMD measurement (Figure 7)[2,5,7,9-11,13].

Strengths of DXA

The principle advantage of DXA is the very low level of radiation that is emitted to patients (1-6 μSv), which is equal to only a few hours of exposure to natural radiation (2,400 μSv per annum). Additionally, with appropriately trained technical staff, this technique has high reproducibility (CVs for lumbar spine 1%; femoral neck 2%; total hip 1%; distal third of the radius 1%) but it requires an interval time of ≥2 years between DXA procedures to detect statistically significant changes in areal BMD[3,4]. Moreover, DXA is easily applied to anatomical sites that are relevant to osteoporotic fractures and the BMD values obtained by DXA are related to fracture risk. The scanning of this method is very rapid and scanners are broadly available around the world. Last but not least, DXA can also be used in pharmacologic and clinical research in order to assess therapy's response[2,4,7].

Limitations of DXA

People who interpret and report a DXA examination should be careful with some technical limitations of DXA. Areal BMD measurements from DXA are bone size-dependent, a fact that results in an overestimation of density in larger bones and an underestimation of density in smaller bones[2]. This limitation is considered a significant problem when this technique is used in children who are in the growing phase. Another limitation of this technique is the heterogeneity of density due to previous fracture or scoliosis/osteoarthrosis, usually in lumbar spine in older people, that may conduce to a rise of density but not to skeletal strength[2-4]. Additionally, it should be mentioned that all high-density material in the path of the DXA X-ray beam is assumed to be bone. Two other technical limitations of DXA are that scanning beds have a weight limitation (typically 300 lb) and also the width of the scanning area (60 cm)[3]. In conclusion, appropriate position of patient, accurate analysis of the scan, avoidance of errors and pitfalls that can show up, could lead to a proper diagnosis and therapy[2,4].

Which site to choose and for which patients

As already shown, there are a number of potential limitations in different individuals that make the result of DXA untrustworthy for further analysis. In the international instructions of IOF, ISCD and in the Greek guidelines[19-21], in the texts or in the tables of them, it is mentioned when a DXA measurement is taken into account and mainly when a measurement is not acceptable. For example, it is suggested that all men and women >65 years should be tested for osteoporosis with DXA, and measurements should be initially performed at the lumbar spine and hip. However, DXA results of the lumbar spine cannot be evaluated in cases of severe spondylarthritis, scoliosis, previous fractures of the lumbar spine, artifacts (piercings, vertebroplasty cement, calcifications superimposed), vertebral ligation etc (Figure 8). In such cases, measurements of the hip are only taken into consideration.

To patients who suffer from intertrochanteric fractures

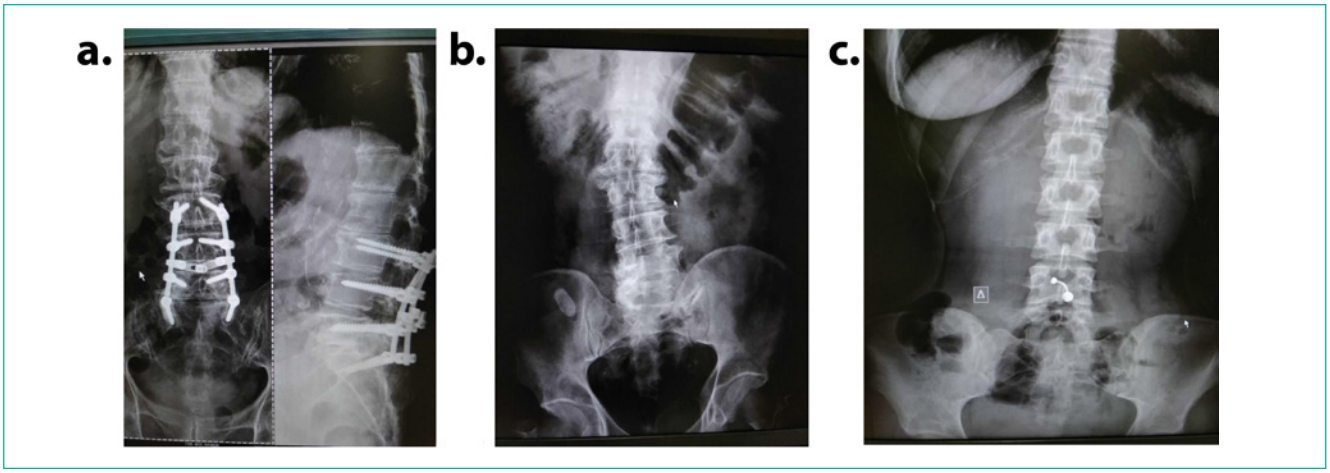

Figure 8. DXA images of patients with: **a.** vertebral ligation, **b.** scoliosis, **c.** artifacts-piercings.

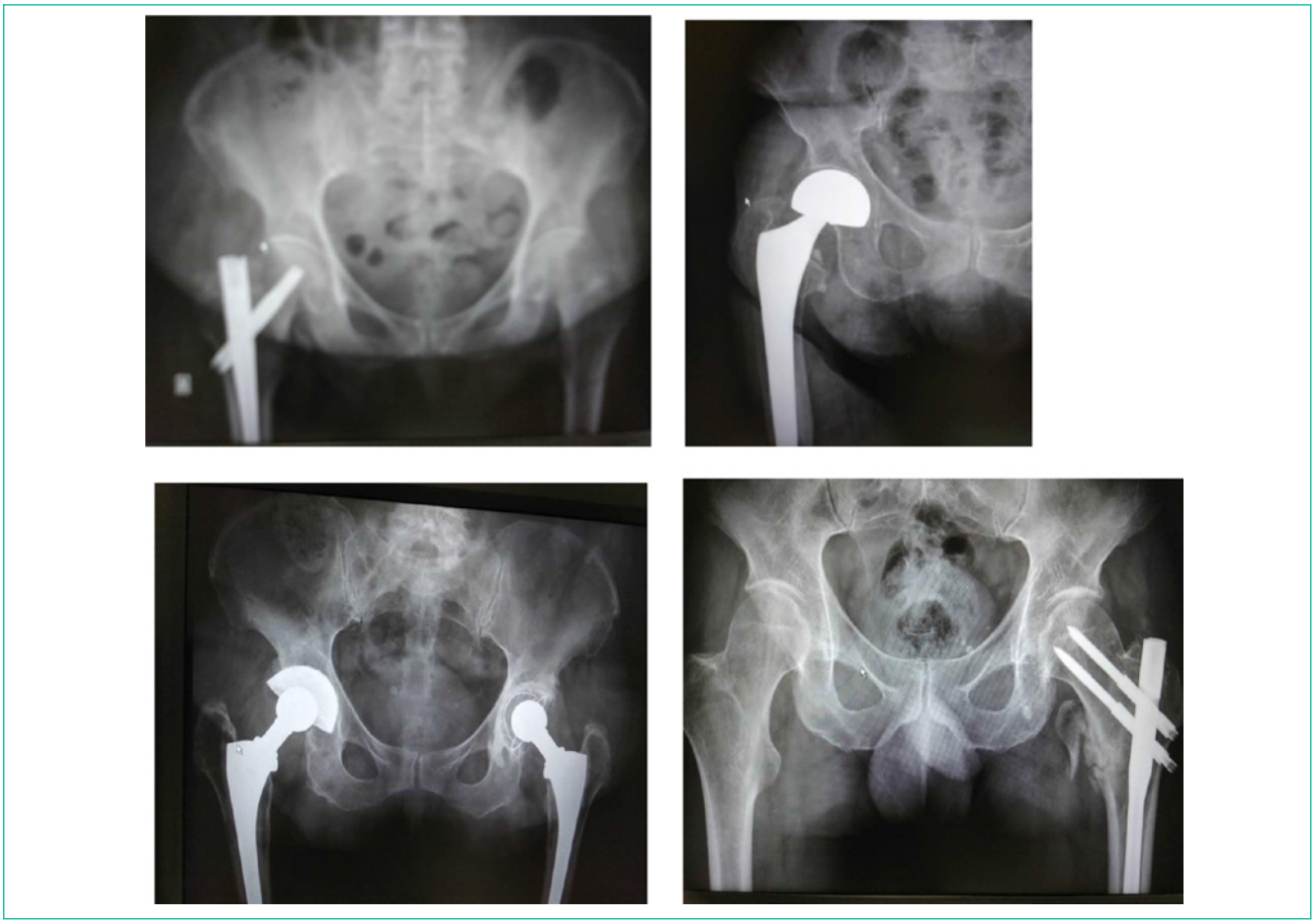

Figure 9. DXA images of patients with intertrochanteric fractures or intramedullary nailing in one or both hips.

or intramedullary nailing, in one or even both hips, it is recommended to do the DXA measurement at lumbar spine and not at the hip (Figure 9).

The official positions according to International Society for Clinical Densitometry (ISCD) and WHO for bone mineral testing (BMD) relate to women aged 65 and older, postmenopausal women under 65 with fracture risk factors and women during the menopausal transition with clinical fracture risk factors (high risk medication use, low body weight), men aged 70 and older, men under 70s years with clinical risk factors for fracture and in general adults with a fragility fracture, disease associated with low bone loss or bone mass, obese people etc. The skeletal sites that are recommended for all patients are firstly both PA spine and hip. Forearm should be measured only under certain circumstances such as if there is a case of hyperparathyroidism or obesity or if one of the previous ROIs cannot be interpreted[15,16].

In postmenopausal women and in men of 50 years and older, osteoporosis may be diagnosed in case that the T-score of lumbar spine, total hip or femoral neck is -2.5 or less. For the diagnosis, other hip regions of interests, such as including Ward's area and the greater trochanter, should not be used[8,15-18]. As a routine, both hip and PA spine should be measured in Postmenopausal (Caucasian) women. Vertebrae, are rich in trabecular bone and there is bigger possibility for them to get affected to a greater degree than regions that are rich in cortical bone (like femoral neck). In addition, basing the diagnosis of osteoporosis only in the measurement of one site, it is not precise as there is possibility some degenerative changes and aortic calcification to occur that can raise the BMD level (of the spine) and so their diagnosis will not be correct. Last but not least, when it comes to fracture risk, since the prediction of BMD is highest for the particular site where it is measured, measuring both sites will prevent both types of fractures[5].

In men from 50 to 64 years old, osteoporosis can be diagnosed if both the T-score is at or below -2.5 and also other fracture risk factors are identified[15-17].

In females before Menopause (age 20 to menopause) and males younger than 50 years, the WHO criteria may be applied only in healthy patients of the first group but diagnosis of osteoporosis should not be made on the basis of densitometry criteria alone in the second group. Patients of this group with secondary causes of low BMD (hypogonadism, glucocorticoid therapy, hyperparathyroidism) may be also diagnosed with osteoporosis by findings of low BMD. In addition, in these two groups, T-scores are not preferred, but Z-scores are used. The use of Z-score instead of T-score is happening to point out that WHO criteria cannot be applied[8,15-18]. In the case of children and adolescents, in order to assess areal BMD, the most preferred and accurate skeletal sites are PA spine and TBLH. Whole body scans and soft tissue measures can also help in the evaluation in case of malnutrition or muscle and skeletal deficits (idiopathic juvenile osteoporosis). The hip (total hip and proximal femur) and the forearm region are not reliable enough in growing children due to the variability in skeletal development and lack of reproducible ROIs. T-scores should not appear in DXA reports and the diagnosis of osteoporosis should not be based only on BMD criteria[8,16].

Sometimes, the hip and/or spine BMD measurements cannot give accurate results like in case of patients with severe scoliosis and degenerative changes, obesity (over the weight limit for DXA table), bilateral hip replacements, patients with extensive spinal instrumentation and multiple compression fractures. On these occasions, forearm can be used as ROI for a DXA measurement. The forearm BMD can be used for the patients who are at a primary level of hyperparathyroidism. Due to the fact that in this condition, cortical bones are more vulnerable in bone loss than trabecular bones, and that the mid-forearm region contains mostly cortical bones, DXA measurement in forearm is well suited for this purpose[5,8].

Osteoporosis is a chronic disease that represents a major clinical problem which has a non-negligible impact on quality life due to the possible occurrence of fractures. It is mandatory to be properly diagnosed in order to prevent its clinical onset. DXA is widely recognized as an accurate, low-cost, quick imaging method and is considered the "gold standard" for the noninvasive pre-fracture diagnosis of osteoporosis and will probably remain so for the next future. It constitutes the standard of reference in evaluating BMD and is effective in following up patients over time. In order to get an accurate report and analysis of DXA examinations and measurements, it is essential to obtain a proper DXA scan with all the required information, such as exact patient demographic information, correct positioning of patient (symmetry, morphology, positioning), ROI placement, and accurate scan analyzing. These things, together with evaluation of bone mineral density and the avoidance of errors and pitfalls/incidental findings that may occur can lead to a proper diagnosis and therapy[2,7,11].

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