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# Osteoporosis Imaging in the Geriatric Patient

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## Abstract

Given the expected rapid growth of the geriatric world population (=individuals aged >65 years) to 1.3 billion by 2050, age-related diseases such as osteoporosis and its sequelae, osteoporotic fractures, are on the rise. Areal bone mineral density (aBMD) by dual-energy X-ray absorptiometry (DXA) is the current gold standard to diagnose osteoporosis, to assess osteoporotic fracture risk, and to monitor treatment-induced BMD changes. However, most fragility fractures occur in patients with normal or osteopenic aBMD, indicating that factors beyond BMD impact bone strength. Recent developments in DXA technology such as TBS, VFA, and hip geometry analysis are now available to assess some of these non-BMD parameters from the DXA image. This review will discuss the use of DXA and DXA-assisted technologies and their respective advantages and disadvantages. Special attention is given to if and how each method is indicated in the geriatric population, and the latest ISCD 2015 guidelines have been incorporated.

### Keywords

ISCD; FRAX; Aging; Geriatrics

## Introduction

### The Geriatric Patient

For millennia, mankind has struggled with the aging of the human body. The first depictions of age-related diseases such as osteoporosis date back to ancient Egypt (2800 B.C) in which the hieroglyphic for “old” was symbolized by a bent person leaning on a staff [1•]. However,

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Compliance with Ethics Guidelines

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it was not until 1909 when the neologism “Geriatrics,” derived from the Greek words γήρας (geras, old age) and ἰατρός (iatros, physician, iatrikos, relating to the physician), was introduced by Ignatz Nascher. He suggested that “as Pediatrics covered the medicine of childhood, the field of Geriatrics should be assigned a separate place in medicine, covering the medicine of old age in order to emphasize the necessity of considering senility and its disease apart from maturity” [2]. The care of geriatric patients—usually defined as any men or women over the age of 65 [3]—has since flourished with the formation of professional societies and specialized training programs that certify dedicated geriatricians. Despite these advances, the demand for high-quality geriatric care, which includes appropriate diagnostic imaging, is higher than ever before and will continue to rise. In its latest prospect of 2015, the United Nations (UN) reported a current worldwide total of 608 million women and men aged 65 years and older [4]. By 2020, the number of people aged 65 years and older is expected to surpass the number of children younger than five years for the first time and reach a staggering 1.3 billion by 2050 [4].

## Osteoporosis: Background and Epidemiology

Given this expected rapid growth in the geriatric world population, diseases and conditions that primarily impact older individuals are and will be of substantial medical and socioeconomic importance [5]. One such condition is osteoporosis (from Greek: fragile or porous bone, ὀστέον (oston, bone), πόρος (pore)), which afflicts about 4 % of men older than 65 years and 26 % of women older than 65 years [6].

As osteoporosis is an age-related disease, nearly 75 % of osteoporotic fractures occur in individuals aged 65 years and older [7], and the lifetime risk of sustaining an osteoporotic fracture in women aged 50 years and older is 50 % [8]. Although osteoporosis is generally regarded as a disease of women, the lifetime risk of osteoporotic fracture in men is also remarkable: 27 % of men older than age 50 years will sustain an osteoporotic fracture in their remaining lifetime [9]. This is more than double the male lifetime risk of developing prostate cancer (11.3 %) [10]. As longevity continues to increase globally, the lifetime risk of osteoporotic fractures will also continue to rise [11]. With 8.9 million osteoporotic fractures estimated to occur annually worldwide, an osteoporotic fracture occurs across the globe every 3 s [12]. These estimates are concerning because osteoporotic fractures precipitate a rapid downward spiral in physical health: 20 % of all patients sustaining a hip fracture will die within 1 year after their trauma and 20 % will need permanent nursing home care [8]. Furthermore, in addition to this significant morbidity and mortality associated with osteoporotic fractures, treatment of osteoporotic fractures has significant economic ramifications. For example, by 2025, treatment costs for osteoporotic fractures in the U.S. alone are expected to exceed $25 billion [5].

## Osteoporosis: Definition and Diagnosis

During the last century, several definitions for osteoporosis have been proposed, and this can be confusing for anyone new to the field (see for further review the recent article of Lorentzon et al. on the evolution of diagnosis of osteoporosis [13••]). The most widely accepted definition of osteoporosis that is still in use was issued in 2000 by a National

Institutes of Health (NIH) expert panel [14]. According to this so-called “NIH consensus osteoporosis definition,” osteoporosis is a skeletal disorder that is characterized by a systemic impairment of bone strength predisposing a person to an increased risks of fragility fractures [14]. The definition further suggests that the determinants of bone strength encompass not only bone mineral density (BMD) but also bone quality. Bone mineral density is generally measured in absolute values as grams mineral Hydroxyapatite (HA), per area of bone (=areal BMD as measured by DXA, see below), or per volume of bone (volumetric BMD as measured by quantitative computed tomography (QCT), or other peripheral QCT methods such as high-resolution peripheral quantitative computed tomography (HR-pQCT)). However, BMD can also be expressed as standard deviation (SD) scores which allow one to compare the individual's results to a reference range. The umbrella term *bone quality* describes the set of characteristics that influence bone strength such as bone macroarchitecture (geometry: size and shape), bone microarchitecture (trabecular architecture, cortical thickness/porosity), bone turnover, accumulation of bone damage (e.g. localization, extent of micro-fractures), and mineralization [14].

Since there is currently no accurate measure of overall bone strength, BMD measurements derived from dual-energy X-ray absorptiometry (DXA) testing (see below) are currently used as the universal gold standard to diagnose osteoporosis. For this purpose, the World Health Organisation (WHO) published in 1994 the criteria that clarify under which circumstances the diagnosis of osteoporosis should be established [15]: these criteria are based on *T*-scores of aBMD by DXA. A *T*-score indicates how many standard deviations (SD) of aBMD an individual's aBMD is apart from the aBMD of a young, healthy, sex- and ethnicity-matched reference population. For example, a *T*-score of −3.5 in a 70-year-old patient signifies that the patient's aBMD by DXA is 3.5 standard deviations below the BMD of a healthy young reference population of the same sex and ethnicity. According to the WHO criteria, a *T*-score less than −1 and greater than −2.5 should be defined as osteopenia, while the diagnosis of osteoporosis should be made only if the *T*-score is −2.5 or lower [15]. Initially, this WHO definition was developed only for postmenopausal women. However, the International Society for Clinical Densitometry (ISCD) has modified and expanded the definition to men as well. Thus, in its latest official position of June 2015, the ISCD recommends that a diagnosis of osteoporosis should be made “in postmenopausal women and in men age 50 or older if the *T*-score (by DXA) of the lumbar spine, total hip or femoral neck is −2.5 or less” [16••] (see also http://www.iscd.org/official-positions/2015-iscd-official-positions-adult/). ISCD further recommends that BMD may be measured at either hip and that the lowest *T*-score of either site, the femoral neck or the total proximal femur, should be reported. Other hip regions of interest such as Ward's area or the greater trochanteric area should not be used for diagnosing osteoporosis [16••]. Although aBMD by DXA (as expressed by *T*-scores or absolute areal BMD values) can be regarded as the main parameter for diagnosing osteoporosis, the diagnosis of osteoporosis should also be made clinically as soon as one or more low-impact fractures occur, even in the absence of BMD measurements [17–19]. A low-impact or fragility fracture is defined as any fracture that results from a low-energy trauma as it occurs when falling from standing height or less or from a bone that breaks under conditions that would not cause a normal bone to break [20]. Thus, the presence of a low-energy trauma fracture is diagnostic for osteoporosis,

irrespective of the patients' BMD. Interestingly, many fragility fractures are sustained in individuals with DXA-derived aBMD in either normal or in the osteopenic range [21–23], suggesting that aBMD by DXA reflects only one facet of overall bone health and that other indicators of bone health (e.g., clinical factors and bone structural measures such as bone geometry or bone microarchitecture) should also be considered for fracture risk assessment. In this review, the use of state-ofthe-art imaging techniques for osteoporosis such as dual-energy X-ray absorptiometry (DXA) are discussed and the use of recently developed DXA-assisted technologies such as Trabecular Bone Score (TBS), Vertebral Fracture Assessment (VFA), and hip geometry analysis are reviewed. In light of the latest 2015 ISCD guidelines, special attention is given to if and how each method is indicated in the geriatric population.

## Assessment of Fragility Fractures on Radiographs

Standard skeletal radiographs can be used to diagnose osteoporotic fractures and in particular vertebral fractures. However, the effective dose of a lateral radiograph of the lumbar and thoracic spine is approximately 600 μSv [24]. Another shortcoming is that radiographs are not sensitive enough to detect early osteoporotic changes before they result in fractures or to quantify these changes objectively. Estimates suggest that 20–30 % of the bone mineral must have been removed before an experienced radiologist will subjectively "recognize" osteoporosis [25••].

## Dual-Energy X-ray Absorptiometry (DXA)

In order to overcome these shortcomings, dual-energy X-ray absorptiometry (DXA) was introduced in the mid-1980s [26–29]. Since then, DXA has established itself as the most widely used bone densitometry technique and as the gold standard in assessing skeletal health in clinical routine. This is mainly due to its pertinent advantages: it is a low-cost, easy-to-use, well-standardized technique, that allows in vivo quantification of aBMD of the central and peripheral skeleton with short scan times (10–30 s), high precision (max. acceptable precision error is 2–2.5 %), and with low radiation doses for the patient (effective doses vary between 1 and 20 μSv, depending on the manufacturer and the scan mode [30]). For the patient's benefit, patients can eat normally on the day of the DXA exam and can take their medication on the day of the scan as usual. However, they should refrain from taking any calcium containing tables for at least 24 h before the exam, as these tablets can overly the spine and cause false BMD elevations. In addition, patients should not have undergone within the last 10–14 days any examinations where they received radio-contrast media orally or intravenously (such as barium or iodine based compounds during a contrast CT), as these contrast agents can also affect BMD measurements.

Unlike its predecessor DPA (dual photon absorptiometry), which needed radioactive gadolinium to generate the low-energy photon beams [31], DXA itself uses an X-ray tube to generate two energy X-ray beams of different energies: one "low-energy" X-ray beam of 40 keV and one "high-energy" X-ray beam >70 keV. Using two energy beams enables subtraction of the soft tissue component [32]. Both energy beams are then transmitted through the human body, where they become attenuated differently and the remaining attenuation energies of both beams are recorded by a flexible detector arm [33•]. The areal BMD values in $g/cm^2$ are next calculated for the scanned region of interest (ROIs): these can

include the proximal femur (with its subregions of total femur region, femoral neck, intertrochanteric, and trochanteric region), the lumbar spine, and the distal radius (see Fig. 1). According to the latest ISCD 2015 official positions, DXA measurements should be performed in all patients at both sites, the spine and the hip [16••]. The forearm should only be scanned if the hip or spine cannot be measured (e.g., due to total joint replacement or degenerative changes), or in hyper-parathyroid or very obese patients (over the weight limit for the DXA table) [16••]. For evaluation of the spine region of interest, the ISCD 2015 recommends using all evaluable vertebrae and excluding only those vertebrae that are affected by local structural changes or artifacts. aBMD-based diagnostic classification should not be made using a single vertebra [16••]. For assessment of hip aBMD, aBMD may be measured at either hip. Additionally, femoral neck or total proximal femur BMD should be used whichever is lowest. Further instructions for correct patient positioning, evaluation, and reporting of DXA scans can be found under [16••, 34] or in the officially recommended ISCD study material [35, 36].

Areal BMD by DXA has been shown to strongly correlate with biomechanically assessed bone strength (about 70 % of the bone strength are explained by BMD) [14]. Even more importantly, aBMD measurements by DXA emerged as strong predictors of fracture risk, in both women and men [37, 38], and the predictive ability of spine and femoral neck aBMD by DXA remained strong even in women aged 80 years and over [39]. For example, one SD decrease in aBMD of the proximal femur increases the relative risk of sustaining a hip fracture in women aged 65–79 years by 190 %, and in women aged 80 years and over by 110 % [39]. These data suggest that aBMD measurements by DXA are useful for all geriatric patients and even in the very elderly population and that in particular this population segment may benefit most from prevention and treatment of osteoporosis. ISCD 2015 official positions reflect these findings and recommend that aBMD testing by DXA is indicated in any women aged 65 years and older and in any men aged 70 years and older. For any men <70 years of age, BMD testing is also indicated if he experiences an additional risk factor for low bone mass. Such a risk factor includes low body weight (BMI of <20 kg/m), a prior fragility fracture, high-risk medication use (e.g., the ever use of corticosteroids) or any disease or condition associated with bone loss [16••, 40]. As treatment of osteoporosis can markedly reduce fracture risk [41] even in very elderly populations [39, 42], follow-up DXA measurements every 1–2 years are frequently carried out in clinical routine to monitor treatment response. However, controversy surrounds the indications and recommended frequency of repeat DXA testing [43]. Unfortunately, the current ISCD official position of 2015 lacks to comment on when and at which frequency follow-up DXA scans are indicated, and leaves it up to the reporting physician of the initial DXA report to comment on the necessity and timing of potential follow-up scans. ISCD does, however, point out that any follow-up DXA report should include a statement about the least significant change (LSC)—a measure of reproducibility that is specific to the DXA facility where BMD measurements are being carried out. If the measured change in aBMD between baseline and follow-up DXA scan is larger than the provided LSC, the BMD change should be considered as genuine, and treatment alterations may be enacted [44, 45].

DXA does have some notable limitations. First and foremost, DXA is only a two-dimensional (2D) technique that quantifies only areal BMD (in grams per square

centimeter). DXA does not provide volumetric (3D) BMD measurements (in milligrams per cubic centimeter) as they can be derived from any quantitative computed tomography techniques such as QCT, pQCT, or HR-pQCT. In addition, DXA does not offer information about the three-dimensional bone microstructure/architecture (e.g., cortical porosity) nor does it differentiate cortical and trabecular BMD. Areal BMD by DXA is also dependent on bone and body size, leading to erroneous overestimation of fracture risk in small patients [46]. Obesity, on the other hand, goes along with larger precision errors and reduced reproducibility [47, 48]. This needs to be considered when interpreting DXA results of obese patients, particularly of patients with larger changes in body composition such as bariatric patients in which hip aBMD by DXA seems specifically prone to weight loss-induced artifacts [49]. Proper patient positioning and image analysis are also critical: spine and hip DXA aBMD measurements are susceptible to degenerative changes which are very common in the elderly (e.g., lumbar spine osteophytes or aortic calcifications) and will falsely elevate BMD and underestimate the true fracture risk in these patients [50]. Moreover, it is crucial to check DXA images for artifacts (e.g. surgical clips, radio-opaque tablets, residuals of radiopaque contrast dye) as they can impact BMD results [51].

## Fracture Risk Assessment Tool (WHO-FRAX)

Because of these limitations and in order to improve fracture prediction, the World Health Organization launched in 2008 the WHO Fracture Risk Assessment tool (FRAX), a web-based tool available online under (www.shef.ac.uk/FRAX/) or downloadable as mobile and desktop application under (www.iofbonehealth.org/osteoporosis-musculoskeletal-disorders/osteoporosis/diagnosis/frax-information-and-resources). This web tool combines clinical information on well-validated osteoporotic risk factors with DXA aBMD of the femoral neck in order to predict the 10-year probability of hip fracture and major osteoporotic fractures (wrist, humerus, hip, and clinical spine fracture) for both women and men [52, 53]. Eleven clinical risk factors are integrated in the FRAX algorithm including age, sex, weight, height, history of previous fracture and of rheumatoid arthritis, history of parental hip fracture, smoking, alcohol use, glucocorticoids, and disorders associated with secondary osteoporosis. Since fracture probability varies notably between different regions of the world (e.g., countries like Iceland and Denmark have a very high fracture risk and countries like Turkey and Chile have a low fracture risk [54]), separate FRAX models are available for different countries and different geographic regions (Europe, Asia, the Middle East, Africa, as well as Northern and Latin America). It is important that the user first calibrates the FRAX model to the patient's home country, or, if this is not possible, to a surrogate country of the same fracture risk epidemiology before entering the clinical information [53]. The latest guidelines issued by the National Osteoporosis Foundation recommend starting osteoporotic treatment in those postmenopausal women and men age 50 and older who demonstrate low bone mass by DXA (*T*-score between −1.0 and −2.5, osteopenia) at the femoral neck, total hip, or lumbar spine and show a 10-year FRAX hip fracture probability >3 % or a 10-year FRAX major osteoporosis-related fracture probability of >20 % (these probabilities are based on the U.S.-adapted WHO absolute fracture risk model) [55]. Although the worldwide usage of FRAX is steadily increasing with more than 2 million calculations per index year [56], a recent meta-analysis reported only a fair performance in predicting the 10-year probability of hip fractures for FRAX without aBMD (women AUC

of 0.74, men AUC of 0.71) and for FRAX with aBMD in both genders (in women AUC of 0.79, men 0.71) [57]. These findings demonstrate that clinical fracture risk assessment and DXA-derived aBMD as combined in FRAX cannot capture the full extent of hip fragility fractures. Other readily available and non-invasively measureable determinants of bone strength such as bone geometry and bone microarchitecture need to be taken into account to more reliably predict osteoporotic fracture risk.

## Adjuncts to Standard DXA Testing: TBS, VFA, and Hip Geometry Analysis

In an attempt to achieve a more accurate identification of individuals at higher fracture risk using readily available clinical techniques such as DXA, several novel tools all based upon DXA images have been developed over the last few years. These adjuncts to standard DXA testing include the (vertebral) trabecular bone score (TBS), the vertebral fracture risk assessment (VFA), as well as DXA-derived hip geometry parameters.

## Trabecular Bone Score (TBS)

First described in 2008 by Pothuaud et al. [58], Trabecular Bone Score is a gray-level textural index that can be derived from standard lumbar spine two-dimensional DXA images using dedicated software (TBS iNsight, Medimaps, Plan-les-Quates, Switzerland) [59•]. It relies on the principle that a lumbar DXA image is a 2D projection of the scanned spine and its vertebra and that it can, therefore, be decomposed in thousands of two-dimensional pixels (picture elements), each of which has an assigned gray value. As trabeculae are rarified in an osteoporotic vertebra, the 2D-projection of such a vertebra will generate an image with a low number of pixel-to-pixel gray variations, but of high amplitude (see for further detail Silva et al. [59•]). In healthy bone instead, the trabeculae form a dense mesh that produces, when projected onto a 2D plane, an image with a large number of pixel-to-pixel variations of small amplitude. By assessing the gray value and the degree of spatial dependency for each pixel and its neighboring pixels, the TBS software calculates a variogram for each vertebra as the sum of the squared gray-level differences between pixels at a specific distance. TBS (unitless) is then computed as the slope of the log–log transform of this variogram with the slope characterizing the rate of gray-level amplitude variations [59•]. A dense trabecular structure results in a 2D image with a high number of pixel gray value variations and therefore a steep variogram slope and a high TBS value. Porous, osteoporotic trabecular bone produces a low variogram slope and consequently, a low TBS value [59•, 60]. TBS software has been FDA approved (http://www.accessdata.fda.gov/scripts/cdrh/devicesatfda/index.cfm?db=pmn&id=K121716) and can be installed on the latest generation of DXA scanners (Prodigy and iDXA of GE Lunar, Madison, WI, or Discovery, Delphi, QDR4500, and Horizon models from Hologic, Bedford, MA; no compatibility with Hologic Explorer). TBS values are usually reported for each vertebra separately and for the total spine (L1–L4). Analogous to DXA-derived lumbar BMD measurements, abnormal or fractured vertebrae can be excluded from the TBS analysis. Retrospective analysis of DXA images is also possible and not time consuming (~5–10 min per scan), once the DXA scanner, from which the DXA images have been obtained, is calibrated with a phantom.

Recent clinical studies have repeatedly demonstrated that low TBS is associated with a raise in both prevalent and incident fragility fractures in postmenopausal women [61–68] and

older men [69–71]. Furthermore, this predictive ability of TBS is independent of clinical risk factors, FRAX, and DXA aBMD [72]. It is, however, noteworthy that after adjustment for confounders, TBS and lumbar spine aBMD by DXA predicted fractures equally well [68]. In light of these findings and to provide guidance for clinicians, the ISCD has recently for the first time included recommendations on the use of TBS into its 2015 official positions [16••]. Therein, the ISCD acknowledges TBS as being associated with vertebral, hip and major osteoporotic fracture risk in postmenopausal women and with hip and major osteoporotic fracture in men over the age of 50 years. In line with a recent meta-analysis [73], the ISCD further recommends that TBS can be used in association with FRAX and aBMD to adjust the FRAX probability of fracture in postmenopausal women and older men. Such a possibility now exists, as TBS has recently been implemented onto the WHO-FRAX website. However, the ISCD clearly states that TBS should not be used as single measurement to determine therapeutic recommendations [16••]. The ISCD also points out that TBS is not useful for monitoring bisphosphonate therapy in postmenopausal osteoporotic women [16••, 74].

This caution towards TBS is derived from several pertinent disadvantages. First, TBS cutoff values that would allow identification of those subjects at greatest risk of fracture have not been established. Secondly, although TBS claims to be an indirect measure of trabecular bone structure, it is currently still not clear to which extent TBS reflects the status of bone microarchitecture in a patient [74, 75]. A handful of small ex vivo studies have demonstrated correlations between TBS and trabecular microarchitectural parameters such as trabecular number, trabecular spacing, and connectivity density [76–78]. However, human in vivo validation studies are scarce and are either focused on a comparison of TBS with central bone microarchitectural parameters of limited resolution (as obtained by QCT measures) or on comparing TBS with bone microstructure parameters of high resolution, but acquired from peripheral skeletal sites such as with HR-pQCT [79–81]. In addition, TBS showed in these studies only weak correlations to vBMD and trabecular indices at the radius and tibia [82], some of them turning even insignificant after multivariable adjustments [81]. Larger high-resolution cadaveric studies are needed to investigate the level of correlation between TBS and local vertebral microarchitecture (see also [74, 75]). In addition, TBS reproducibility studies found not only a reduced short-term intra-scan precision of TBS in comparison to BMD [83] but also revealed notable inter-scanner differences in TBS values (particularly between standard GE DXA scanners and higher resolution models such as iDXA), despite an excellent inter-scanner agreement for BMD [84]. Given these current limitations, TBS values acquired at different densitometers should not be directly compared to each other and serial TBS scans should only be obtained at the same DXA instrument [84]. Further work on quality control (development of specific TSB phantom, scanner cross-calibration) and additional clinical studies are needed to determine whether TBS will be appropriate for clinical use.

## Vertebral Fracture Assessment (VFA)

Vertebral fractures are the most common osteoporotic fractures, especially in geriatric patients. Population-based studies show that the prevalence of vertebral fragility fractures in white women aged 65 years and older is about 23.5 % and rises up to 50 % for women aged

≥80 years [85, 86]. Prevalence of vertebral fracture in men is also high, ranging from about 20 % in men aged 65 years and older to over 39 % in men aged ≥80 years [85, 86]. Since a first vertebral fracture not only increases an individual's risk for subsequent vertebral fracture by fivefold [87, 88] but also increases the risk to sustain a future non-vertebral osteoporotic fracture [89], and since osteoporotic therapies can reduce the incidence of future fractures, it is crucial that vertebral fractures are detected and diagnosed correctly and as early as possible. However, spine imaging by plain radiographs is not routinely carried out in patients at risk, due to costs, accessibility, or concerns of radiation (about 600 μSv per lateral spine radiograph). In addition, only about 30 % of all vertebral fractures are symptomatic and come to clinical attention [90]. The major part of osteoporotic vertebral fractures is clinically silent and is randomly detected during imaging studies performed for other clinical reason such as lateral chest X-ray, CT, or MRI or not detected at all [91, 92]. To minimize underreporting, the International Osteoporosis Foundation (IOF) has launched the Vertebral Fracture Initiative. This free teaching program is accessible online to all interested radiologists, clinicians, and other healthcare professionals (www.iofbonehealth.org/what-wedo/training-and-education/educational-slide-kits/vertebral-fracture-teaching-program). It is dedicated to training clinicians in the proper recognition of osteoporotic vertebral fractures using different imaging techniques including conventional radiography, DXA-based Vertebral Fracture Assessment (VFA), or other spinal imaging techniques such as MDCT and MRI. Although this present review will mainly focus on VFA (see recent reviews by Link et al. [93] and Griffith et al. [94••] for further reading on the radiologic assessment of vertebral osteoporotic fractures), it is crucial to understand that the osteoporotic vertebral fracture assessment in any of the aforementioned modalities is performed using the same standardized, universally accepted, visual semi-quantitative grading system by Genant et al. [95••]. To diagnose a vertebral osteoporotic fracture with this grading system, the physician evaluates visually the shape and height of each vertebra in the sagittal plane (either lateral radio-graph/DXA-VFA image, or sagittal MDCT reformations, or sagittal MR sequence). A fracture should be reported if there is at least $a \geq$ 20 % visually estimated loss in vertebral body height relative to a normal looking adjacent vertebra. The reduction in vertebral body height can occur either at the anterior edge of the vertebra (leading to a wedge-shaped fracture), or in the middle of the vertebra (creating a biconcave shaped or bow tie fracture), or can involve the posterior edge of the vertebra (resulting in a fracture with crush/compression deformity). The Genant score differentiates between four fracture severities: no fracture, mild, moderate, and severe fracture. It is crucial to mention the severity of a fracture in the radiology report as vertebral fracture severity has been shown to strongly predict disease progression and mirrors the deterioration of bone microarchitecture [96, 97]. While grade 0 is equivalent to “no fracture”, a mild (or grade 1) osteoporotic vertebral fracture is defined as an approximate 20–25 % reduction in anterior, middle or posterior height or a 10–20 % reduction of vertebral area. A moderate or grade 2 fracture requires an approximate reduction of 25–40 % in vertebral height or a 20–40 % reduction in vertebral area. Severe fractures should be diagnosed if the vertebra shows more than 40 % reduction in any vertebral height or vertebral area [95••].

Recent advances in DXA technology have made it possible to evaluate the presence and severity of vertebral fractures not only on conventional radiographs, MDCT, and MRI but

also on spine images acquired via DXA [98]. This densitometric lateral spine imaging technique is called vertebral fracture assessment (VFA, Fig. 2). Depending on the manufacturer, different acronyms for the same technique such as lateral vertebral assessment (LVA), anterior vertebral assessment (APVA), dual vertebral assessment (DVA), instant vertebral assessment (IVA), or radiologic vertebral assessment (RVA), circulate in the literature. However, the usage of these terms is officially discouraged by ISCD [98]. VFA uses standard DXA scanners to obtain lateral and frontal images of the entire spine in near-radiographic quality in a short amount of time (between 1 and 10 min, depending on scanner model) [99]. The vertebrae inferior to T7 (T7–L5) are then routinely assessed for fractures using the Genant grading system and via automated vertebral morphometric analysis (MXA). Like plain spine radiography, VFA can detect moderate to severe vertebral fractures with high accuracy [100], while detection of mild fracture with VFA seems less reliable relative to plain radiography [101]. Several studies have demonstrated the added diagnostic and therapeutic value of combined VFA and DXA aBMD testing [102, 103]. Olenginski et al. reported that VFA detected in 34 % of patients aged 65 years and older vertebral fractures [102]. Further evidence by Greenspan et al. demonstrated that 11–18 % of all patients would have been misclassified as “normal” by the use of aBMD alone, while the additional application of VFA resulted in the clinical diagnosis of osteoporosis and influenced patient management [103]. This and further evidence [104] suggest that VFA is a useful tool to decrease misclassification and prevent potential mismanagement of osteoporosis. This is particularly noteworthy, as VFA has certain other pertinent advantages that make it promising for clinical use, namely VFA can be conveniently performed at the time of bone densitometry testing by DXA at low cost [105]. Moreover, VFA uses only a fraction of the radiation dose incurred by plain radiography (2–50 μSv for VFA versus 600 μSv in conventional spinal radiographs [24]). Current ISCD official positions (2013 and 2015) therefore recommend lateral spine imaging with either standard radiography or with densitometric VFA in all women aged ≥70 years and all men aged ≥80 years who display a DXA *T*-score of less than −1.0 [16••, 106•]. Moreover, VFA or lateral spine radiography is indicated in all women and men of any age with a *T*-score less than −1.0 in whom one or more of the following risk factors are present: a historical height loss exceeding 4 cm (>1.5 in.) [107], a prior vertebral fracture (self-reported, undocumented) [108], and a glucocorticoid therapy equivalent to ≥5 mg of prednisone or equivalent per day for ≥3 months [109].

## Hip Geometry Analysis

Several bone geometry parameters can be derived from the DXA image of the proximal femur. These include the measurement of the hip axis length (HAL, which is defined as the length of a line drawn to connect the inner pelvic brim to the lateral margin of the femoral shaft below the greater tro-chanter [110]) and the determination of the neck-shaft angle (NSA, defined as the angle between femoral neck axis and femoral midshaft axis [111]). Depending on the scanner, additional parameters such as cross-sectional area (CSA), cross-sectional moment of inertia (CSMI), buckling ratio (BR), or section modulus (SM) can be routinely obtained from DXA scans using commercially available software packages such as Hip Structural Analysis (HSA, from Hologic) [112] or Advanced Hip Assessment (AHA, from General Electrics). While HAL has been shown in multiple populations to predict the

risk of hip fracture in post-menopausal women independent of BMD [110, 113, 114] and FRAX [115], data on the predictive value of HAL in men is scarce. In line with these findings, the latest ISCD guidelines of 2015 acknowledge that HAL is only a good predictor of hip fracture risk in postmenopausal women, but not in men [116]. However, a recently published study by Leslie et al. in the Manitoba cohort provides the first evidence that HAL is also predictive of incident hip fracture in both men and women, independent of BMD or FRAX [117]. Like HLA, NSA, and other hip geometry parameters including buckling ratio and section modulus have been found to predict hip fracture in postmenopausal Caucasian women [114, 118–121]. However, to date, it is not yet clear if this risk is independent of BMD. Due to this reason and other reasons [116], the latest guidelines issued by ISCD in 2015 do not support the use of NSA or any other DXA-derived hip geometry parameters (CSA, OD, DM, BR, CSMI) in clinical practice to neither assess fracture risk nor start or monitor osteoporotic treatment [116].

## Conclusion

Geriatric individuals (age >65 years) currently make up 608 million of the world population and this demographic is estimated to grow to 1.3 billion by 2050. Given this expected rapid growth in the geriatric world population, the burden of age-related diseases such as osteoporosis, which affects one in two women and one in five men aged >50 -years, will be substantial. Correct and early diagnosis of osteoporosis using state-of-the-art imaging is and will be essential to start patients on anti-osteoporotic therapy and to prevent future osteoporotic fragility fractures and associated morbidity and mortality. Areal Bone mineral density (aBMD) measurement by dual-energy X-ray absorptiometry (DXA) is most widely accessible and will remain for the foreseeable future the imaging procedure of choice to diagnose osteoporosis, assess osteoporotic fracture risk, and monitor BMD changes resulting from anti-osteoporotic treatment. Due to recent advances in DXA technology, additional measurements can be extracted from DXA images, including trabecular bone score (TBS), vertebral fracture risk assessment (VFA), and hip geometry parameters such as hip length axis (HLA) or neck-shaft angle (NSA). However, the role of these DXA-assisted technologies in clinical diagnosis has still to be determined.

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•• Of major importance

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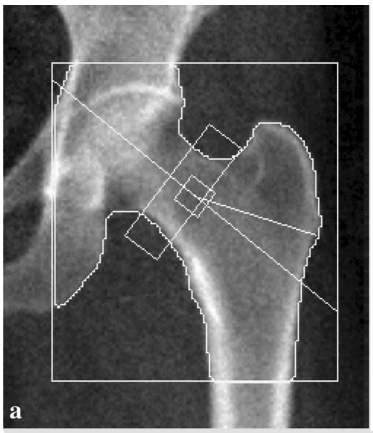
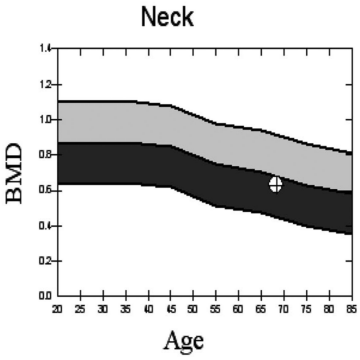
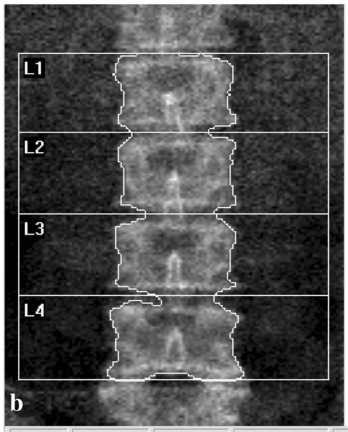
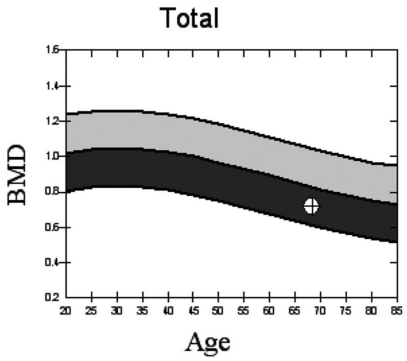



| Region | Area[cm²] | BMC[(g)] | BMD[g/cm²] | T-score | PR (Peak Reference) | Z-score | AM (Age Matched) |
|---|---|---|---|---|---|---|---|
| **Neck** | **4.41** | **2.78** | **0.630** | **-2.1** | **72** | **-0.4** | **92** |
| Troch | 10.04 | 5.29 | 0.527 | -1.7 | 75 | -0.5 | 91 |
| Inter | 20.36 | 18.90 | 0.928 | -1.2 | 82 | 0.0 | 99 |
| Total | 34.81 | 26.96 | 0.775 | -1.4 | 81 | -0.1 | 99 |
| Ward's | 1.16 | 0.49 | 0.421 | -2.5 | 57 | -0.4 | 89 |




| Region | Area[cm²] | BMC[(g)] | BMD[g/cm²] | T-score | PR (Peak Reference) | Z-score | AM (Age Matched) |
|---|---|---|---|---|---|---|---|
| L1 | 12.57 | 9.67 | 0.769 | -2.0 | 78 | -0.2 | 97 |
| L2 | 12.86 | 9.59 | 0.746 | -2.6 | 73 | -0.6 | 92 |
| L3 | 13.02 | 8.93 | 0.686 | -3.6 | 63 | -1.6 | 80 |
| L4 | 14.31 | 9.77 | 0.683 | -3.4 | 64 | -1.3 | 83 |
| **Total** | **52.76** | **37.96** | **0.720** | **-3.0** | **69** | **-1.0** | **87** |

**Fig. 1.**

Representative DXA studies of **a** the proximal femur and **b** the lumbar spine of a 68-year-old woman. The lowest *T*-score of total and femoral neck regions of interest is used to grade the bone as normal, osteopenic, or osteoporotic. **a** In this postmenopausal woman, the *T*-score of the proximal femur was −2.1 which is in the osteopenic range according to the WHO osteoporosis definition. **b** L1–4 DXA image of the lumbar spine in the same postmenopausal women (68 years). The total *T*-score of the lumbar spine involving L1 to L4 is −3.0 and therefore in the osteoporotic range. Please note the discordance between the two

*T*-scores as they fall into different, but adjacent classes (osteopenic versus osteoporotic). Priority is given in this case to the osteoporotic *T*-score and the patient should be diagnosed as osteoporotic

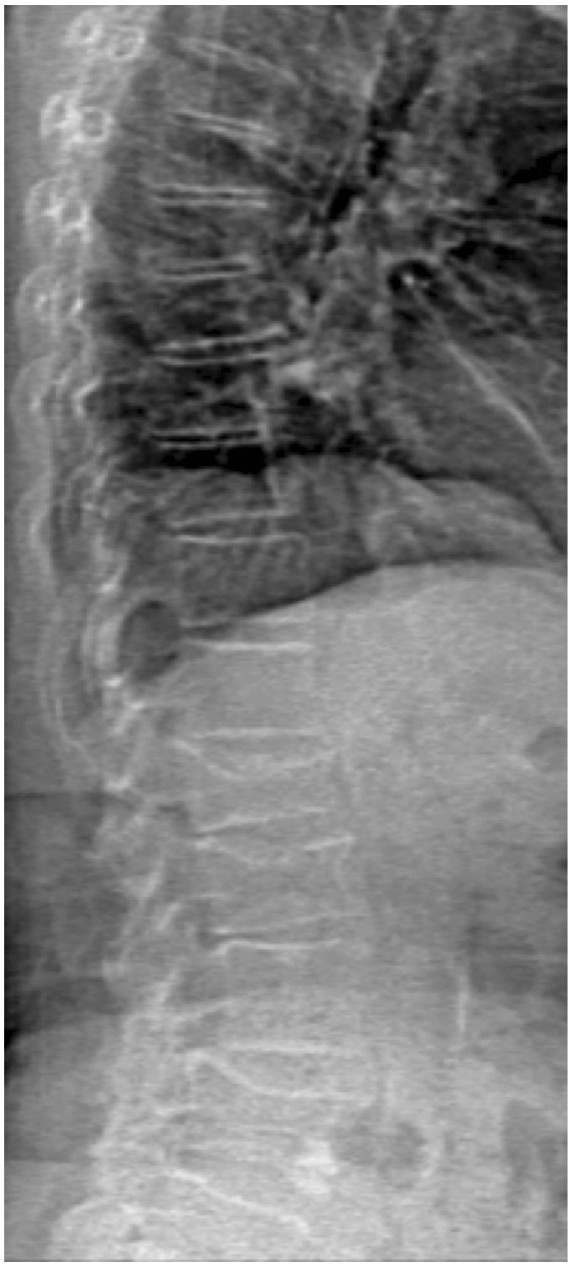


**Fig. 2.**
Representative vertebral fracture assessment (VFA) image of the spine obtained with DXA showing multilevel osteoporotic fractures at the lumbar spine