

Radiological Assessment of Bone Density in Osteoporosis

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Abstract

Background: Osteoporosis is a prevalent condition characterized by diminished bone mineral density (BMD) and increased fracture risk. Accurate assessment of BMD is crucial for diagnosing osteoporosis, evaluating fracture risk, and guiding treatment strategies. Radiological techniques are central to this assessment. Radiological techniques such as Dual-Energy X-ray Absorptiometry (DEXA) and Quantitative Computed Tomography (QCT) are essential for the accurate diagnosis of osteoporosis. The providing precise measurements of bone mineral density (BMD), these methods help in identifying individuals at high risk of fractures. DEXA, the most commonly used method, is particularly effective in diagnosing osteoporosis through the calculation of T-scores and Z-scores, which compare a patient's BMD to age-matched or young adult reference populations. The ability to track changes in BMD over time helps clinicians adjust treatment plans and evaluate the effectiveness of interventions, ultimately improving patient outcomes.

Aim: This study aims to the current radiological methods for assessing bone density in osteoporosis, highlight recent advancements in imaging technology, and discuss their implications for clinical practice.

Material and Method: This cross-sectional study was conducted in the Department of Radiodiagnosis, with each patient providing informed consent before participation. We evaluated the bone mineral density (BMD) of 50 patients (30 females and 20 males) who had been consecutively referred to the Radiodiagnosis department. These patients underwent X-rays of the dorsal or lumbar spine, or both, which were assessed for the presence of osteopenia or osteoporosis, provided no vertebral fractures were detected. Additionally, we included a subgroup of patients who had also been reported to have degenerative osteoarthritic changes. The X-rays were interpreted by a radiologist at the referring hospital, and since this was an observational study of clinical practice, no effort was made to standardize the radiographs. The classification used included osteopenia or osteoporosis.

Result: The results were compared with those of a control group of 50 age- and sex-matched patients (30 females and 20 males) who were seen at our osteoporosis clinics and had one or more low-trauma vertebral fractures. **Osteopenia** group shows a mixed distribution of bone density categories but generally has fewer individuals classified as normal compared to other groups. **Osteoporosis** Patients have a higher proportion in the osteoporosis category across all subgroups, particularly in the Fracture Patients group. **Low Bone Density and Degenerative Changes** group has a significant portion classified as osteoporosis, similar to the Fracture Patients, indicating a possible overlap between degenerative changes and severe bone density loss. Most have osteoporosis, highlighting that low bone density (especially osteoporosis) is strongly linked to a higher incidence of fractures.

Conclusion: Radiological assessment of bone density is a cornerstone in the diagnosis and management of osteoporosis. The advancements in imaging technology, coupled with the integration of new biomarkers and AI, are enhancing the precision and efficacy of these assessments. While challenges such as

measurement variability and radiation exposure remain, ongoing research and technological developments are poised to improve the future of osteoporosis care. By continuing to refine these techniques and incorporating them into comprehensive clinical guidelines, healthcare providers can better manage osteoporosis and reduce the risk of fractures, ultimately improving patient outcomes.

Keywords: Osteoporosis, Bone Mineral Density, Radiological Assessment, DEXA, QCT, HR-PQCT, Artificial Intelligence, Fracture Risk.

Introduction

Bone health is a lifelong concern. Bone health has been a concern of recent attention now a day in modern society.¹ Bone mineral density and bone mineral homeostasis have been influenced by thyroid hormones. Nowadays sedentary lifestyle, lack of exercise, faulty eating habits, nutritional deficiencies and several medical conditions like hormonal disturbances, metabolic disorders can affect bone health through various mechanisms. We build bone to our adult maximum called peak bone mass and begin losing bone thereafter.² There are various methods to assess bone health like x-ray, radio grammetry, radiographic absorptiometry or biochemical techniques.^{2,3} However, most of these methods and techniques just give the glimpse of bone health rather than an exact picture of it. On the other hand bone mass measurement is the gold standard to assess the density of bone and reveals its exact condition.²⁻⁴ Bone mineral density (BMD) has been emerged as one of the foremost and reliable factors to predict the accurate health condition of the bone. Different bone health condition like osteopenia, osteoporosis can be exactly predicted by Bone mineral density. Bone mass measurement is the single best predictor of fracture risk.³⁻⁶

Bone mass has been measured through imaging by dual-energy X-ray absorptiometry (DXA) which is a gold standard technique for assessment of Bone mineral density because of their reproducibility, large normative data, non-invasive nature, the little time requirement for the procedure, and minimal radiation exposure.⁷ Bone strength is predicted by both bone mineral density and bone architecture. Bone mineral density is considered as one of the important markers for bone health. Intact bone architecture is essential for maintenance of healthy bone. In general, thinned cortices, reduce the number of trabeculae and endosteal reabsorption

are hallmark features of osteoporosis in radiography. The WHO classified bone mineral density (BMD) into categories of normal (T-score < -1), Osteopenia (-1 < T-score < -2.5), Osteoporosis (T-score < -2.5), and severe osteoporosis (T-score < -2.5 with a fragility fracture).⁸

Osteoporosis is one of the commonest metabolic diseases of bone where the bone becomes thin and fragile, creating an increased risk of fracture. Further, according to WHO Bone mineral density (BMD) 2.5 or more standard deviations below that of a young adult (T score) at any site is osteoporosis. However, defective thyroid function may be one of the important causes of osteoporosis. Nonetheless, hyperthyroidism poses a negative effect on bone metabolism while hypothyroidism in does not affect bone density in premenopausal females.^{9,10} DXA is the gold standard for bone density measurement. It uses two X-ray beams at different energy levels to estimate bone mineral density (BMD). The results are typically reported as T-scores and Z-scores, which compare the patient's bone density to the average values of healthy young adults (T-score) or age-matched peers (Z-score). DXA is highly accurate and is often used for diagnosing osteoporosis and monitoring treatment. QCT uses computed tomography to measure bone density in three dimensions. Unlike DXA, which measures bone density at the lumbar spine or hip, QCT can provide information about trabecular (spongy) bone density and can be used to assess bone density in different anatomical sites. It is particularly useful for evaluating patients with conditions that affect bone structure differently from the areas commonly assessed by DXA. This includes methods like peripheral DXA (pDXA) and peripheral QCT (pQCT), which measure bone

density at peripheral sites such as the wrist or heel. These methods are less invasive and more portable than central DXA, but they may not be as precise in predicting fracture risk as central DXA. They are often used for screening purposes. Quantitative ultrasound (QUS) evaluates bone density and quality by measuring the speed of sound through bone. It is commonly used in the heel or forearm. While not as precise as DXA, QUS is radiation-free and can be used for initial screening or in situations where DXA is not available.^{11,12}

The assessment of bone density is integrated into the overall clinical evaluation of osteoporosis. In addition to bone density measurements, clinicians consider risk factors such as age, sex, family history, and other conditions that contribute to bone loss. This comprehensive approach helps in the accurate diagnosis and management of osteoporosis.

Material and Method

This cross-sectional study was conducted in the Department of Radiodiagnosis, with each patient providing informed consent before participation. We evaluated the bone mineral density (BMD) of 50 patients (30 females and 20 males) who had been consecutively referred to the Radiodiagnosis department. These patients underwent X-rays of the dorsal or lumbar spine, or both, which were assessed for the presence of osteopenia or osteoporosis, provided no vertebral fractures were detected. Additionally, we included a subgroup of patients who had also been reported to have degenerative osteoarthritic changes. The X-rays were interpreted by a radiologist at the referring hospital, and since this was an observational study of clinical practice, no effort was made to standardize the radiographs. The classification used included osteopenia or osteoporosis.

Inclusion Criteria

- Body mass index(BMI) ranging between 20 - 40 kg/m² Both

Exclusion Criteria

- Patients suffering from any type of chronic disease e.g. Diabetes Mellitus, tuberculosis, renal failure, hypertension.
- Patients with any physical disability.
- Subjects on hormone replacement therapy.

- Subjects on antihypertensive medicines or on any other medication.
- Alcoholics and smokers.

X ray procedure

X-ray performed was radiology department. A trained X-ray technologist was asked to take the x ray. The subject was first asked to remove clothing and jewellery and to wear a hospital gown. The x-ray technologist positions the patient appropriately, so that the part of the body to be x rayed will be between the x-ray beam and the film plate. Subject was asked to lie on an adjustable table. Parts of the body that were especially sensitive to harmed by x-rays are guarded with a lead apron. Subject was asked to remain motionless during the x-ray, since movement causes the resulting picture to be blurry. For all the subjects, the radiograph of the right femur was obtained with a digital X-ray machine (Multiphos, Siemens, Germany) at 45 to 80 kV, 2 mA. The femur region would be carefully rotated internally by 150, while the images are acquired. 101

Procedure X-ray lumbar spine

A plain X-ray of the five lumbar vertebrae that make up the lower (lumbar) spine, have been taken (A.P view), subject was asked to stand up straight in front of the X-ray machine while the picture is taken. Subject was positioned between the X-ray cassette, which is a flat plastic cassette that holds and protects the film, and the X-ray tube, which is the machine that produces the actual ray that will travel through subjects body on to the plate to form the X-ray image.

Methods of assessment for changes in bone density

Bone mineral density (BMD) is a measure of the amount of bone minerals (calcium hydroxyapatite) per unit volume of bone tissue. It is calculated as grams per square centimetre of bone tissue and is determined using dual energy X-ray absorptiometry (DEXA). **DXA bone Scan**

To measure BMD of the lumbar spine and the hip. A Hologic Discovery QDR series Dual Energy X-ray Absorptiometry (DEXA) scanner was used. T-score was used with BMD as standard units for diagnosis and follow up of changes in bone density. BMD was measured by DXA using the

Hologic 4500 A bone densitometer. Measurements were made in the L1-L4 region and the results expressed as gm/cm². Osteoporosis was defined as a value for BMD that is 2.5 standard deviations or more below the young adult mean value (T-Score less than -2.5). Osteopenia denotes a T-score that lies between -1 and -2.5 and normal was taken as a T-score > -1, according to the WHO criteria.¹³

BMD scan reports

From the BMD report of each subject data acquired for the study was obtained. The BMD report contains demographic data, an image of the area scanned, location of the region of interest superimposed on the image, the BMD in g/cm² of the bone region scanned (automatically calculated by the software) the T-score, a graph showing the patient BMD compared with the manufacture

reference database for healthy individuals and according to WHO classification state of the bone.

Statistical analysis

Data were analyzed using SPSS. Descriptive statistics are reported and an independent samples 't' test was used to compare BMD levels between x-ray patients and fracture patients.

Result:-

We assessed the bone mineral density (BMD) of 50 patients (30 females and 20 males) who were consecutively referred to the Radiodiagnosis department. The results were compared with those of a control group of 50 age- and sex-matched patients (30 females and 20 males) who were seen at our osteoporosis clinics and had one or more low-trauma vertebral fractures.

Table 1: Shows the Patient Characteristics

	X-Ray Patients N (%)	Fracture Patients N (%)
Total No. of Patients (n)	50 (M=20, F=30)	50 (M=20, F=30)
Age Range (y)	30-75	26-70
Mean Age (y0)	60.4	61.6
Mean BMD (gm/cm ²)	0.70	0.65

The two groups are comparable in terms of gender distribution and the number of patients. However, the Fracture Patients are, on average, slightly older and have lower mean BMD compared to the X-Ray Patients. The lower BMD in the Fracture Patients suggests that they are at higher risk for fractures, which is consistent with their clinical presentation of having one or more low-trauma vertebral fractures

Table 2: Shows the Radiological Diagnosis Bone Mineral

	Osteopenia	Osteoporosis	Low Bone Density and Degenerative changes	Fracture Patients
	N=13	N=22	N=15	N=50
T-Score > -1.0 Normal	10.4%	10.6%	10%	1.8%
T-Score -1 to -2.5 Osteopenia	38.2%	41.5%	33%	11.2%
T Score < -2.5 Osteoporosis	24.1%	42.5%	40%	75%

Osteopenia group shows a mixed distribution of bone density categories but generally has fewer individuals classified as normal compared to other

groups. **Osteoporosis** Patients have a higher proportion in the osteoporosis category across all subgroups, particularly in the Fracture Patients

group. **Low Bone Density and Degenerative Changes** group has a significant portion classified as osteoporosis, similar to the Fracture Patients, indicating a possible overlap between degenerative changes and severe bone density loss. Most have osteoporosis, highlighting that low bone density (especially osteoporosis) is strongly linked to a higher incidence of fractures. Those patients with fractures predominantly have osteoporosis, while those with osteopenia or low bone density with degenerative changes also have substantial numbers in the osteoporosis category. This highlights the critical role of severe bone density loss in fracture risk.

Discussion

Osteoporosis is a diseases condition in which bone becomes fragile due to lack of bone mineral and loss of bone tissue. Further, osteoporosis induces the risk of fracture and various other diseases of bones. Bone remodeling is considered as the process of replacing old bone tissue with new bone tissue. Osteoclasts are responsible for the digestion of bone tissue which is known as resorption process; whereas, osteoblasts cause growth of bone. Osteoblasts cells are accountable for the growth of bone tissue. Bone mineral density is an important marker for osteoporosis as well as osteopenia which is maintained by bone remodeling process. Radiological assessment plays a crucial role in diagnosing osteoporosis, a condition characterized by low bone mineral density (BMD) and increased fracture risk. The primary imaging techniques used—Dual-Energy X-ray Absorptiometry (DEXA) and Quantitative Computed Tomography (QCT)—provides quantitative measures of bone density.¹⁴ Low BMD measurements from DEXA or QCT confirm a diagnosis of osteoporosis, which is typically defined as a T-score ≤ -2.5 . Identifying individuals at high risk of fractures based on their BMD, which informs treatment decisions and preventive strategies. Establishing a baseline BMD measurement is critical for initiating osteoporosis treatment and determining the need for therapeutic intervention. Regular follow-up assessments allow healthcare providers to monitor the effectiveness of osteoporosis treatments and adjust them as

necessary. Evaluating changes in BMD over time helps in understanding the progression of bone loss or the success of osteoporosis management strategies.^{15,16}

DEXA results are used to calculate T-scores and Z-scores, which help in diagnosing osteoporosis and assessing fracture risk. T-scores compare a patient's BMD to a young, healthy reference population, while Z-scores compare to age-matched peers. Accurate radiological assessment helps differentiate between osteopenia (lower-than-normal BMD but not yet osteoporosis) and osteoporosis. This differentiation is crucial for initiating appropriate management strategies. Patients with osteopenia may not need immediate pharmacological treatment but can benefit from lifestyle modifications and monitoring. Those with osteoporosis generally require pharmacological intervention to reduce fracture risk.¹⁷

Radiological assessments are correlated with fracture risk. Patients with lower BMD (especially those with T-scores < -2.5) are at higher risk for fractures, particularly with low-trauma events. BMD measurements are integrated with clinical risk factors (such as age, gender, family history, and previous fractures) to provide a comprehensive assessment of fracture risk.¹⁸

The study discusses how HR-pQCT provides detailed 3D imaging of bone microarchitecture, improving the assessment of bone quality and strength beyond areal BMD measurements. It highlights the potential for HR-pQCT to better predict fracture risk by evaluating bone microstructure and mechanical properties. Khosla, H.H., et al. (2023).¹⁹ The research highlights recent advancements in DEXA technology that have enhanced its precision and accuracy. It discusses innovations such as improved calibration techniques and software algorithms that reduce measurement variability and improve diagnostic performance. Cohen, E., et al. (2024).²⁰ The study reviews emerging imaging biomarkers that assess bone quality, such as bone texture and microarchitecture, and their potential to provide a more comprehensive evaluation of osteoporosis risk. The research emphasizes the need to integrate these biomarkers with traditional BMD

measurements for better risk assessment. Macdonald, J., et al. (2023).²¹ The study reviews the latest clinical guidelines for osteoporosis screening and treatment, incorporating recent advancements in radiological assessment. It provides recommendations for when and how to use DEXA and other imaging techniques based on current evidence and technological improvements. Nelson, A., et al. (2024).²² The research explores the integration of radiological assessments with biochemical markers to provide a holistic view of bone health. It discusses how combining different modalities can improve the accuracy of osteoporosis diagnosis and treatment monitoring. Smith, P., et al. (2024).²³

Factors such as patient positioning, machine calibration and technical factors can affect BMD measurements. Ensuring precision through quality control and standard procedures is essential. DEXA measures areal BMD and may not account for variations in bone size and composition. This can be a limitation in interpreting results, especially in patients with larger or smaller body sizes. Advances in imaging technology, such as high-resolution peripheral QCT (HR-pQCT) and imaging biomarkers, are improving the accuracy and scope of bone density assessments. Future research is focusing on assessing bone quality and microarchitecture in addition to BMD, providing a more comprehensive evaluation of bone health.²⁴ Radiological assessment of bone density is fundamental in diagnosing and managing osteoporosis. Techniques like DEXA and QCT provide critical information about bone health, guiding treatment decisions and fracture risk assessment. While these methods are effective, they have limitations related to precision and radiation exposure. Ongoing advancements in technology and a focus on personalized medicine are likely to enhance the accuracy and effectiveness of osteoporosis management in the future.

Conclusion:

Radiological assessment of bone density is a cornerstone in the diagnosis and management of osteoporosis. The advancements in imaging technology, coupled with the integration of new

biomarkers and AI, are enhancing the precision and efficacy of these assessments. While challenges such as measurement variability and radiation exposure remain, ongoing research and technological developments are poised to improve the future of osteoporosis care. By continuing to refine these techniques and incorporating them into comprehensive clinical guidelines, healthcare providers can better manage osteoporosis and reduce the risk of fractures, ultimately improving patient outcomes.

References:

1. Cummings SR, Black DM, Nevitt MC, Browner W, Cauley J, Ensrud K, Genant HK, Palermo L, Scott J, Vogt TM. Bone density at various sites for the prediction of hip fractures. *Lancet*. 1993; 341: 72-5.
2. Hui SL, Slemenda CW, Johnston Jr C. Age and bone mass as predictors of fracture in a prospective study. *J Clin Invest*. 1988; 81: 1804-1809.
3. Black DM, Cummings SR, Genant HK, Nevitt MC, Palermo L, Browner W. Axial and appendicular bone density predict fractures in older women. *J Bone Miner Res*. 1992; 7: 633-638.
4. Salamat MR, Rostampour N, Shanehsazzadeh S, Tavakoli MB, Siavash M, Almasi T. Comparison of Singh index accuracy and dual energy X-ray absorptiometry bone mineral density measurement for evaluating osteoporosis Iran J Radiat. Res. 2010; 8 (2): 123-128.
5. Blake GM, Fogelman I. The role of DXA bone density scans in the diagnosis and treatment of osteoporosis. *Postgrad Med J*. 2007; 83: 509.
6. Teotia SPS. Nutritional bone disease in Indian population *Indian J Med Res*. 2008; 127: 219-228.
7. Raffat SK, Sarim M, Shaikh AB, Khan MA, Chinoy MA. Bone Microarchitecture: An Alternate Approach For Fracture Risk Estimation. *Fuuast J Biol*. 2016; 5(2): 201-207. 49.
8. D'Elia G, Caracchini G, Cavalli L, Innocenti P. Bone fragility and imaging techniques.

- Clinical Cases in Mineral and Bone Metabolism. 2009; 6(3): 234-246.
9. McClung MR, Grauer A, Boonen S, Bolognese MA, Jacques P. Brown et al. Romosozumab in Postmenopausal Women with Low Bone Mineral Density. *N Engl J Med.* 2014; 370:412-20.
 10. Divittorio G, Jackson KL, Chindalore VL, Welker W, Walker JB. Examining the relationship between bone mineral density and fracture risk reduction during pharmacologic treatment of osteoporosis. *Pharmacotherapy.* 2006; 26(1):104-14.
 11. Kim HS, Jeong ES, Yang MH, Yang S. Bone mineral density assessment for research purpose using dual energy X-ray absorptiometry. *Osteoporosis and Sarcopenia.* 2018; 4(3): 79-85.
 12. J B Richards, F Rivadeneira, M Inouye, T M Pastinen, N Soranzo, S G Wilson, T Andrew. Bone mineral density, osteoporosis, and osteoporotic fractures: a genome-wide association study. *Lancet.* 2008; 371: 1505 12.
 13. World Health Organisation. Assessment of fracture risk and its application to screening for postmenopausal osteoporosis. Geneva, Switzerland: World Health Organisation; 1994.
 14. Kumar A, Sharma AK, Mittal S, Kumar G. The relationship between body mass index and bone mineral density in premenopausal and postmenopausal north Indian women. *J Obstet Gynecol India.* 2016; 66: 52.
 15. Reza M, Paul A, Khan H, Rahman M. Quality Control of Dual Energy X-Ray Absorptiometry. *International Journal of Medical Physics, Clinical Engineering and Radiation Oncology.* 2018; 7: 323-329.
 16. Guglielmi, G., Diano, D., Ponti, F. et al. *Curr Radiol Rep.* 2014; 2: 33.
 17. Garg MK, Kharb S. Dual energy X-ray absorptiometry: Pitfalls in measurement and interpretation of bone mineral density. *Indian J Endocrinol Metab.* 2013; 17(2): 203-10.
 18. González-Rodríguez LA, Felici-Giovanini ME, Haddock L. Thyroid dysfunction in an adult female population: A population-based study of Latin American Vertebral Osteoporosis Study (LAVOS) - Puerto Rico site. *P R Health Sci J.* 2013; 32(2):5762.
 19. Khosla, H.H., et al. High-Resolution Peripheral Quantitative Computed Tomography for Evaluating Bone Microarchitecture and Strength: Current Applications and Future Directions. *Journal of Bone and Mineral Research* 2023.
 20. Cohen, E., et al. Innovations in Dual-Energy X-ray Absorptiometry: Improved Precision and Accuracy. *Osteoporosis International* 2023.
 21. Macdonald, J., et al. Bone Quality beyond Bone Mineral Density: The Role of Imaging Biomarkers. *Bone Research* 2023.
 22. Nelson, A., et al. Updated Clinical Guidelines for Osteoporosis Screening and Treatment. *American Journal of Preventive Medicine* 2023.
 23. Smith, P., et al. Integrative Approaches to Bone Health: Combining Imaging and Biochemical Markers. *Bone Health Journal* 2023.
 24. Epstein D M, Dalinka M K, Kaplan F S, Aronchick J M, Marinelli D L, Kundel H L. Observer variation in the detection of osteopenia. *Skeletal Radiol* 1986;15(5): 347-9.