Section: Radiology

Original Research Article

THE ADVANTAGES OF MEASURING LUMBAR VERTEBRAL BODY ATTENUATION IN ROUTINE ABDOMINAL CT SCANS OVER CONVENTIONAL DEXA SCAN

Vishal Gupta[1], Saurav Bhagat[2], Amit Kumar Gupta[3], Dev Kumar[4], Nandisha Gupta[4], Shaleen Girdhar[4]

[1]Professor & Head, Department of Radiology, School of Medical Science and Research, Sharda University, Greater Noida, Uttar Pradesh, India.
[2]Assistant Professor, Department of Radiology, School of Medical Science and Research, Sharda University, Greater Noida, Uttar Pradesh, India.
[3]Associate Professor, Department of Radiology, School of Medical Science and Research, Sharda University, Greater Noida, Uttar Pradesh, India.
[4]Junior Resident, Department of Radiology, School of Medical Science and Research, Sharda University, Greater Noida, Uttar Pradesh, India.

Received : *05/01/2023*
Received in revised form : *09/02/2023*
Accepted : *24/02/2023*

Keywords:
Lumbar vertebral body, HU value, Abdominal CT, DEXA

Corresponding Author:
Dr. Dev Kumar
Email: dr.devkrchaudhary@gmail.com

DOI: 10.47009/jamp.2023.5.2.184

Source of Support: Nil,
Conflict of Interest: None declared

Int J Acad Med Pharm
2023; 5 (2); 869-874

Abstract

Background: Osteoporosis is a common condition among individuals leading to fractures specially in the long bones. Bone mineral density (BMD) values derived from routine lumbar spine multi-detector CT may be used for a population for osteoporosis screening with no additional costs to the patient.
Aim: This study aimed to find a correlation between computed tomography(CT) imaging obtained opportunistically during abdominal CT and dual-energy x-ray absorptiometry(DEXA) scans. **Materials and Methods:** A total of 100 patients who underwent noncontrast abdominal CT for any reason were enrolled in the study. The HU value of each lumbar vertebra was determined by averaging three measurements of the vertebra's trabecular portion, in consecutive axial CT images. DEXA was performed on them using standard techniques with central DEXA BMD T-scores recorded from the lumbar vertebrae. Subjects were categorized as having osteopenia or osteoporosis based upon WHO criteria. **Result:** The mean age of study population was 53.11±16.57 years. There was significant positive correlation of L1, L2, L3 and L4 values of CT hounsfield unit(HU) value with DEXA value on Pearson correlation (r= 0.849 - 0.923) with the maximum correlation at L1 vertebra. The mean CT HU value for the lumbar vertebrae was significantly higher in normal subjects compared to Osteopenia & Osteoporosis subjects. **Conclusion:** This study shows that L1 trabecular attenuation measurements had maximum correlation with DEXA. CT-based HU values can be used as a tool while reporting the abdominal CT scan to serve as screening method or detecting bone mineral diseases like osteoporosis without an extra cost or radiation exposure.

INTRODUCTION

Globally, 1 in 5 men and 1 in 3 women over 50 years is likely to suffer an osteoporotic fracture.[1] India is the second most populated nation in the world with 1.2 billion people, 10% of whom are over 50, increasing the burden of bone diseases including osteoporosis.[2] Osteoporosis increases hip and spine fracture risk due to low bone mineral density (BMD) and quality.[3] Several methods measure bone mineral density including broadband USG, Dual-energy X-ray absorptiometry (DEXA), and quantitative CT scans.[4,5] For the examination of BMD, dual-energy X-ray absorption (DEXA) and quantitative computed tomography (QCT) of the lumbar spine are considered to be the best options.[5] DEXA has lower radiation exposure and is non-invasive. However, body composition, surrounding soft tissue, vascular calcifications, intestinal contents, degenerative spine alterations, patient positioning, data acquisition, analysis, and artefacts might generate errors that can affect bone mass estimates.[6,7,8,9] However, the inner trabecular bone has more metabolic activity than the outer cortical bone, suggesting it is more affected by bone mass changes.[10] A 3D trabecular bone-exclusive technique will improve identifying BMD change evaluation.[11,12,13] Over 90% of clinical DEXA

ISSN (O): 2687-5365; ISSN (P): 2753-6556

examinations had at least one error, with 79% due to poor image processing analysis.[14,15]

CT is used for additional purposes including for opportunistic osteoporosis screening utilizing HU from CT scans to calculate spine bone mineral density.[16,17,18,19,20] Quantitative CT measures skeletal mass, osteoporosis therapy response, and other metabolic bone diseases, therefore serves as the most sensitive osteoporosis detection method.[21,22] It assesses genuine 3-dimensional bone mineral density, not area density, unlike other non-invasive technologies. QCT distinguish central or peripheral trabecular, cortical, or integral bone.[21,22] However, CT was only utilized for research due to its lengthy scanning sessions and greater ionizing radiation doses, despite its precision.[23]

This study aimed to investigate a correlation between computed tomography (CT) imaging obtained opportunistically during a abdominal CT and dual-energy x-ray absorptiometry (DEXA) scans. Currently there is a paucity of evidence on opportunistic CT that limits its broader applicability and use. We hypothesized that CT scan can be a reliable method to screen for patients with bone mineral disease and subsequently evaluate their risks of fractures.

MATERIALS AND METHODS

Study Design

Cross sectional study

Ethical Approval

Clearance from Board of Studies and Ethical committee in the Department of Radiodiagnosis, SMS & R, Greater Noida during the period 2019-21.

Sample Size

The study population has been calculated by using G-power software with 80% of the power and 5% of the significance level. The total sample size was determined to be 100 patients.

Sampling technique and procedure: Simple random sampling technique was used to recruit study participants. A detailed history, complete physical examination and routine & appropriate investigations were done for all patients.

Inclusion Criteria

All patients >25 years of age undergoing non contrast abdominal CT for any reason.

Exclusion Criteria

Patients with lumbar spine fracture or instrumentation, previous vertebroplasty or spinal fusion, or with anatomical deformity (severe kyphosis or scoliosis), or with any malignancy, inflammatory or metabolic diseases.

Study Tools

Imaging

CT Scan

All CT scans were performed with use of a GE helical 128 slice CT scanner (optima 660). The CT parameters include a slice thickness of 0.6 mm, a tube voltage of 120kVp and automatic tube current modulation. Using picture archiving and communication system (PACS) software, measurements of a spherical region of interest (ROI) through the lumbar vertebrae(L1-L4) is performed to establish Hounsfield Unit (HU) values. Measurements for each level is made at three separate locations: anterior vertebral body and mid-vertebral body. The posterior vertebral body was excluded due to the presence of basivertebral vein. The ROI was spherical with a volume of one cubic centimeter and care was taken to avoid the vertebral endplates and anterior cortex. The average value of the three measurements was taken as the HU value of that vertebral level. These values were calculated from L1 to L4 level.

Dual-energy x-ray absorptiometry (DEXA)

DEXA was performed using standard techniques on Lunar Prodigy densitometers (GE medical systems) with fan beam. Central DEXA BMD T-scores was recorded for the lumbar spine. Subjects were categorized as having osteopenia (T-score DEXA between -1.0 and -2.5) or osteoporosis (T-score DEXA< -2.5) based upon WHO criteria.

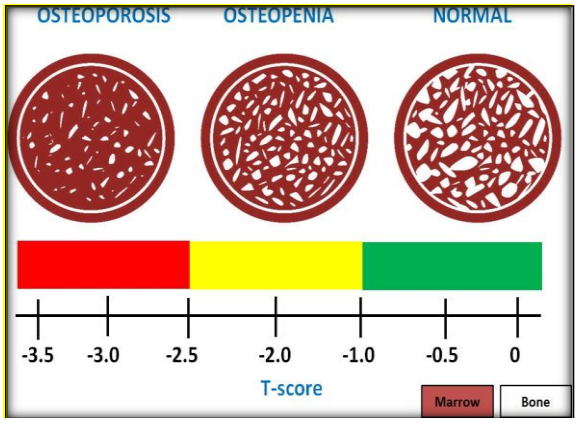

Figure 1: The WHO classification of bone status into three levels based on the T-scores

Normal (T-score > –1), Osteopenia (–2.5 < T-score ≤ –1) and Osteoporosis (T-score ≤ –2.5)

Statistical Analysis

The data was entered into the Microsoft excel and the statistical analysis was performed by statistical software SPSS version 21.0 (IBM Corp., Armonk, NY, USA). The Quantitative were present in the form of mean and SD and the Qualitative (Categorical variables) were present in the form of frequency and percentage. The student t-test was used for comparing the mean values between the two groups whereas chi-square test was applied for comparing the frequency. Pearson correlation (r) was analyzed between DXA BMD and CT HU for different vertebral levels. The p-value was considered to be significant when less than 0.05.

ISSN (O): 2687-5365; ISSN (P): 2753-6556

RESULTS

Table 1: Socio-demographic characteristics of the study participants

Variable		Frequency	Percent (%)
Age	25-35 years	22	22.0
	36-45 years	11	11.0
	46-55 years	17	17.0
	56-65 years	21	21.0
	66-75 years	22	22.0
	> 75 years	7	7.0
	Mean ± SD (Range)	53.11±16.57 (25-86)	
Gender	Male	30	30.0
	Female	70	70.0

The mean age of the study population was 53 years. Approximate one-fourth (22%) of the study participants belonged to 25-35 years, Similar proportion belonged to 66-75 years (22%) while only 7 percent aged more than 75 years. Majority of the them were females (70%).

Table 2: Computed Tomography HU and DEXA value

Vertebral level	CT HU value Mean ± SD (Range)	DEXA value Mean ± SD (Range)
L1	139.56 ± 53.02 (20.00-224.00)	–1.22 ± 1.30 (– 4.50-1.40)
L2	135.13 ± 53.18 (16.00-220.00)	–1.46 ± 1.35 (– 4.90-1.00)
L3	140.24 ± 54.17 (24.00-245.00)	–0.98 ± 1.43 (– 4.40-3.20)
L4	137.79 ± 53.72 (14.00-232.00)	–1.06 ± 1.43 (– 4.80-2.30)
L1-L4	137.73 ± 51.64 (18.00-224.00)	–1.17 ± 1.29 (– 4.50-2.00)

The mean Computed Tomography HU value was 137.73±51.64. It was highest for L3 level (140.24 ± 54.17), while it was lowest for L2 level (135.13 ± 53.18). The mean DEXA value was -1.17±1.29. It was the lowest for L2 level (–1.46 ± 1.35) and highest for L3 level (–0.98 ± 1.43).

Table 3: Pearson`s Correlation of DEXA and CT HU value

Vertebral level	Pearson`s Correlation coefficient (p-value)
L1	0.923 (< 0.001)
L2	0.901 (< 0.001)
L3	0.864 (<0.001)
L4	0.849 (<0.001)
L1-L4	0.895 (<0.001)

There was a significant positive correlation of Computed Tomography HU value with DEXA value for L1, L2, L3, L4 and for the composite L1-L4 level. Highest value of correlation was observed at L1 level (r=0.923; p<0.001).

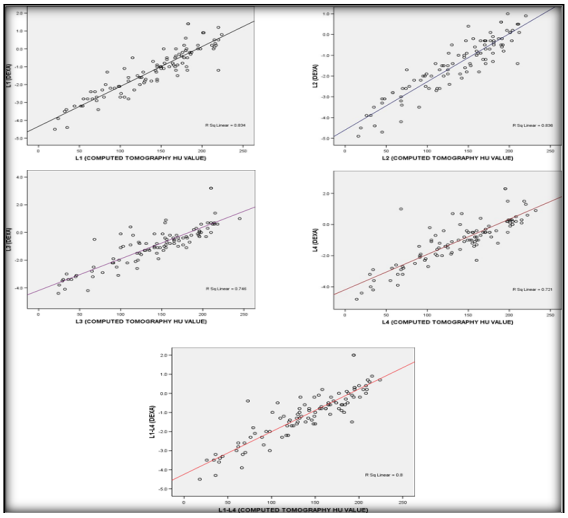

Figure 2: Scatter plots showing strong correlations between CT HU and DEXA for L1, L2, L3, L4 and composite L1-L4 vertebral level

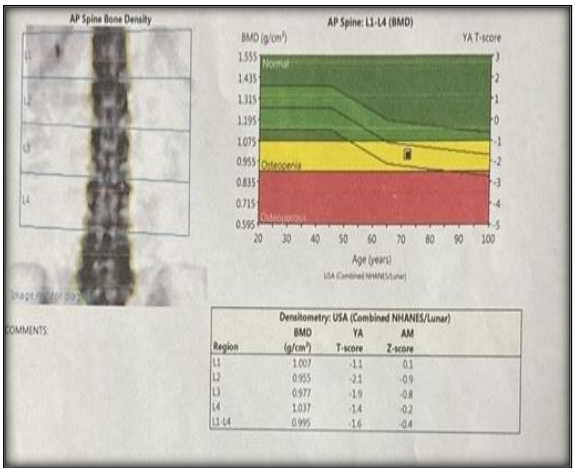

Figure 3 (a): DEXA scan image showed osteopenia with T score at L1, L2, L3, L4 and composite L1-L4.

ISSN (O): 2687-5365; ISSN (P): 2753-6556

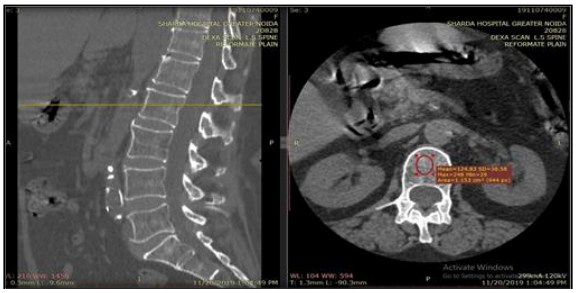

Figure 3 (b): Corresponding CT sagittal reconstruction image and axial image of lumbar spine of the same patient showed mean HU value at L2: 124 ± 38.5.

Table 4: Mean Computed Tomography HU value for L1, L2, L3, L4 and L1-4

Vertebral level	Categorization based on bone mineralization			F-value (p-value)
	Normal	Osteopenia	Osteoporosis	
L1	163.68± 46.42	132.22 ± 39.02	88.41 ± 57.09	17.486 (<0.001)
L2	159.02 ± 45.20	129.94 ± 39.07	80.06 ± 57.66	19.183 (<0.001)
L3	166.02 ± 47.32	133.64 ± 36.51	82.94 ± 57.13	21.293 (<0.001)
L4	163.91 ± 48.97	131.50 ± 31.10	78.88 ± 55.34	23.223 (<0.001)
L1-L4	162.68 ± 45.34	131.42 ± 32.78	82.12 ± 55.10	22.342 (<0.001)

The mean Computed Tomography HU value for L1, L2, L3, L4 and L1-4 was significantly more among Normal subjects compared to Osteopenia which was highly significantly more than Osteoporosis (p<0.001).

DISCUSSION

It was found that diagnostic CT images with automated exposure control can estimate bone mineral density. Due to its low radiation dose (0.009-0.027 mSv) compared to CT (0.06-2.5 mSv), ease of use, and availability, DEXA is used to measure bone mineral density.[24]

Quantitative CT required a density-calibrated phantom. The phantom was scanned with the patient to convert HU values into bone mineral density and calibrate other factors that may affect results. Modern CT scanners have automated exposure control, eliminating the need for quantitative CT calibrating phantoms.[24] DEXA-based T-scores, which is a gold standard is defined by the number of standard deviations below the mean peak bone mass of a young and healthy adult. However, DEXA osteoporosis screening is underutilized, which could lead to fragility fractures, which cause chronic pain and disability and cost the healthcare system a lot of money to treat. Thus, opportunistic CT imaging for osteoporosis screening has grown in popularity.[25]

This study measured lumbar bone density from routine abdominal and lumbar CT scans to diagnose osteopenia and osteoporosis. The results showed that scan density measurements at the L1–L4 vertebra levels can diagnose osteopenia and osteoporosis. L1 has the most accurate spine bone mineral density measurements.[26]

Socio-Demographic Characteristics

The mean age of the study population was 53.11±16.57 (25-86) years. Bauman et al.[27] reported a comparatively lower mean age of 44±13 years. While the mean age was comparatively higher in studies conducted by Booz et al.[28] (58.05±13.0 years), Zhang et al.[29] (68.7 ± 9.4 years), Graffy et al.[30] (78.3 years), indicating that osteoporosis mainly affects people with advanced age.

Owing to advanced age, females develop osteoporosis following menopause due to decreases level of estrogen and progesterone, while males develop bone resorption due to decreased metabolism of testosterone. We found that there were 30 percent males and 70 percent females among study population. Female preponderance was found by Graffy et al.[30] in their study (41% males vs 59% females), similar to the findings of Zhang et al.[29] (47.5% males vs 52.5% females). Whereas, Booz et al.[28] showed similar incidence of osteoporosis among males and females in their study (51% males vs 49% females).

DEXA value and CT HU value

DEXA is considered the main technique for assessment of osteoporosis. DEXA measures bone mineral density by exposing a patient to X-rays with two different energies (usually 40 and 70 keV) and then comparing the intensity of those X-rays and the attenuation coefficients of bone and soft tissue. In the present study we used T-score to establish clinical osteoporosis where the bone mineral density of an individual is compared with that of young healthy sex-matched populations, wherein T-score ≤ –2.5 indicates osteoporosis. CT being comparatively more accurate uses Hounsfield Unit (HU) to define osteoporosis. The present study revealed that the mean T-score was –1.17±1.[29] and the mean CT HU value was 137.73±51.64. A less than quarter (21%) of study participants had osteopenic bone mineral density with a T-score between –1.0 and –2.5 based on DEXA measurements of at least two vertebrae,

ISSN (O): 2687-5365; ISSN (P): 2753-6556

while 42.6 percent had osteoporotic bone mineral density with a T-score of 2.5 or below.

Booz et al.[28] found a comparatively higher DEXA-derived bone density at L1-4 (0.985 ± 0.306 g/cm2). Lee et al.[23] found lower L1-4 HU values (84.7±40.1) and lower T-scores (–1.7±1.49). While, Hendrickson et al.[31] reported a higher L1 to L4 CT HU value (232 ± 41) similar to the present study. Our results matched previously reported lumbar HU values of 248±52 and 222±36 HU among women.[32,33]

Correlation of Computed Tomography HU value with DEXA value

Through this study, we have determined that the bone mineral density measurement provided by DEXA has a significant positive correlation with the CT HU value at L1, L2, L3, L4 and L1-L4 (0.923, 0.901, 0.864, 0.849 and 0.895 respectively) with highest correlation at L1 vertebrae.

Kirzner et al.[25] found a moderate-strong correlation between DEXA lumbar spine and mid-vertebral body CT HU, with L3 having the strongest correlation (r2=0.7269). In another study by Schreiber-coauthored study lumbar CT HU value correlated with DEXA for BMD and T-score. HU values and T-score were moderately correlated by Alawi et al.[24] Liu et al.[34] examined a cohort of chronic spinal cord injury patients using qCT of the L-spine and DEXA scan. They revealed that qCT was 2.4±1.1 and DEXA was 1.3±2.3 above the mean, which is similar to the finding reported herein. Thus, patients with decreased bone mineral density can be identified easily during routine CT scans for various reasons and referred for DEXA imaging to determine their bone density category: normal, osteopenia, or osteoporosis. Thus, CT can detect decreased bone density opportunistically.

In general, qCT is more sensitive than DEXA for diagnosing osteopenia and better at predicting fracture risk. qCT is not the best method for serial BMD monitoring due to its lower precision, higher radiation exposure, harder positioning, longer scan time, and higher cost than DEXA.27 Since DECT measures true volumetric BMD in the trabecular bone and DEXA measures areal BMD in both cortical and trabecular bone, for this reason Booz et al.[28] found no statistical correlation between DEXA and DECT values. Our study supported CT screening for low bone density. Low bone density was defined as 150 HU on CT imaging. Our reference value matches previous studies.[23, 26]

Association of Computed Tomography HU value with DEXA scan value

Physicians use DEXA-based T-scores to diagnose osteoporosis. HU values were significantly correlated with T-scores in this study. Thus, HU values may indicate osteoporosis and prompt further studies including DEXA and appropriate patient management. In CT-based screening, knowing the HU values associated with osteoporosis would be helpful. 23 Normal subjects had a significantly higher mean Computed Tomography HU value (162.68±45.34) than Osteopenia (131.42±32.78) and Osteoporosis (82.12±55.10).

Kirzner et al.[25] reported that the normal group had a mean HU value of 139.3, compared to the osteopenic group 105.9 and the osteoporotic group 72.4. Lee et al.[23] found that subjects with normal bone density had a mean lumbar HU value of 120.8, compared to those with osteopenia 78.8, and osteoporosis 54.7. Islamian et al.[35] reported similar mean values of 133.0±37.6, 100.8±24.5, and 78.5±32.4 for normal, osteopenic, and osteoporotic spine bone densities. Schuit et al.[33] found that patients with vertebral fracture had osteopenic and normal DEXA T-scores as well, highlighting DEXA's limitations, particularly in BMD overestimation due to degenerative changes.[26] Aforesaid values could be used to set appropriate ranges.

Our study found low vertebral CT-attenuation values at levels other than fractures, and the fractures were visible on sagittal views. Our study and others have found normal and osteopaenic DEXA T-scores in vertebral fracture patients. Routine CT can detect unsuspected osteoporotic compression fractures, which indicate osteoporosis regardless of DEXA T-score.[35] Few studies found lower diagnostic accuracy in routine CT trabecular vertebral density measurements compared to DXA bone mineral density. Again, DEXA's BMD overestimation due to degenerative changes shows its limitations.[25]

CT scans are a common medical diagnostic tool. Our study was limited by using a single CT scanner and DEXA machine. The results' reproducibility in other CT and DEXA scanners is unknown. The smaller sample size necessitated a large population-based studies to verify results. Further, the one- to two-year gap between CT and DEXA imaging may affect results. The HU values on CT were calculated from trabeculated bone, while DEXA values include cortical bone and trabeculated bone. This can cause a discrepancy between CT and DEXA scan

CONCLUSION

This study correlated dual energy x-ray absorptiometry and computed tomography attenuation of lumbar vertebral trabecular bone. 100 patients were sampled with mean age of 53 years and female predominance. Computed Tomography HU values correlated positively with DEXA values for L1-L4 vertebral levels. Adjusted for normal bone mineral density, osteopenia and osteoporosis, normal subjects had significantly higher Computed Tomography HU values for L1-L4 vertebral levels. Instead of DEXA's AP projection, which captures the posterior cortical bone and potentially pathological bony and vascular structures, qCT isolates and examines the vertebral body's medullary trabecular bone. Advantage of CT scan lies in assessing trabecular bone density in comparison to

ISSN (O): 2687-5365; ISSN (P): 2753-6556

the DEXA scan which assesses the bone density based on combined attenuation of vertebral body and posterior elements. Therefore the CT attenuation data is more likely to accurately measure the risk of fracture assessment as compared to DEXA scan. Thus, it was concluded that bone mineral density values from routine lumbar spine multi-detector CT can reveal the patient's bone density and serve as a reliable tool for measuring HU values for opportunistic osteoporosis screening without additional cost.

REFERENCES

1. Kanis JA, Johnell O, Oden A, Sembo I, Redlund-Johnell I, Dawson A, et al. Long-term risk of osteoporotic fracture in Malmö. Osteoporos Int 2000;11:669-74.
2. Mithal A, Bansal B, Kyer CS, Ebeling P. The Asia-pacific regional audit-epidemiology, costs, and burden of osteoporosis in India 2013: A report of international osteoporosis foundation. Indian J Endocrinol Metab 2014;18:449-54.
3. Van der Klift M, De Laet CE, McCloskey EV, Hofman A, Pols HA. The incidence of vertebral fractures in men and women: the Rotterdam study. J Bone Miner Res 2002;17:1051–6.
4. Fogelman I, Blake GM. Different approaches to bone densitometry. J Nucl Med 2000;41, 2015–5.
5. Anburajan M, Ashok KD, Sapthagirivasan V. Evaluation of osteoporosis in Indian women and men using peripheral dual-energy X-ray absorptiometry (pDXA) IPCBEE. Vol. 5. Singapore: IACSIT Press; 2011.
6. Antonacci MD, Hanson DS, Heggeness MH. Pitfalls in the measurement of bone mineral density by dual energy X-ray absorptiometry. Spine. 1996;21:87–91.
7. Bolotin HH, Sievänen H. Inaccuracies inherent in dual-energy X-ray absorptiometry in vivo bone mineral density can seriously mislead diagnostic/prognostic interpretations of patient-specific bone fragility. J Bone Miner Res. 2001;16:799–805.
8. Bolotin HH. DXA in vivo BMD methodology: an erroneous and misleading research and clinical gauge of bone mineral status, bone fragility, and bone remodelling. Bone. 2007;41:138-54.
9. Messina C, Bandirali M, Sconfienza LM et al. Prevalence and type of errors in dual-energy X-ray absorptiometry. Eur Radiol. 2015;25:1504-11.
10. Engelke K, Adams JE, Armbrecht G et al (2008) Clinical use of quantitative computed tomography and peripheral quantitative computed tomography in the management of osteoporosis in adults: the 2007 ISCD Official Positions. J Clin Densitom 11:123–162.
11. Vetter JR, Perman WH, Kalender WA et al (1986) Evaluation of a prototype dual-energy computed tomographic apparatus. II. Determination of vertebral bone mineral content. Med Phys 13:340–343
12. Wesarg S, Kirchner M, Becker M et al (2012) Dual-energy-CT-based assessment of the trabecular bone in vertebrae. Methods Inf Med 51:398–405
13. Wichmann JL, Booz C, Wesarg S et al (2014) Dual-energy CT-based phantomless in vivo three-dimensional bone mineral density assessment of the lumbar spine. Radiology 271:778–785.
14. Messina C, Bandirali M, Sconfienza LM, D"Alonzo NK, Di Leo G, Papini GD, et al. Prevalence and type of errors in dual-energy X-ray absorptiometry. Eur Radiol 2015;25:1504–11.
15. Genant HK, Boyd D. Quantitative bone mineral analysis using dual energy computed tomography. Invest Radiol. 1977;12:545-51
16. Goo HW. CT radiation dose optimization and estimation: An update for radiologists. Korean J Radiol. 2012;13:1-11.
17. Papadakis AE, Karantanas AH, Papadokostakis G, Petinellis E, Damilakis J (2009) Can abdominal multi-detector CT diagnose spinalosteoporosis? Eur Radiol 19: 172-176.
18. Schreiber JJ, Anderson PA, Hsu WK. Use of computed tomography for assessing bone mineral density. Neurosurg Focus. 2014;37:E4.
19. Tay WL, Chui CK, Ong SH, Ng AC. Osteoporosis screening using areal bone mineral density estimation from diagnostic CT images. Acad Radiol. 2012;19:1273-82.
20. Link TM, Koppers BB, Licht T, Bauer J, Lu Y, et al. In vitro and in vivo spiral CT to determine bone mineral density: Initial experience inpatients at risk for osteoporosis. Radiology. 2004;231:805-11
21. Genet HK. Assessing osteoporosis: CT"s quantitative advantage. Diagn Imag 1985:233–9.
22. Adams JE. Developments in QCT & comparisons with DEXA. RSNA 2000;242
23. Lee S, Chung CK, Oh SH, Park SB. Correlation between bone mineral density measured by dual-energy X-Ray absorptiometry and hounsfield units measured by diagnostic CT in lumbar spine. J Korean Neurosurg Soc. 2013;54:384-9.
24. Alawi M, Begum A, Harraz M, Alawi H, Bamagos S, Yaghmour A, Hafiz L. Dual-Energy X-Ray Absorptiometry (DEXA) Scan Versus Computed Tomography for Bone Density Assessment. Cureus. 2021;13(2):e13261
25. Kirzner N, Gallagher C, Kimmel L, Fischer D, Mc Laurin W, et al. A Comparative Study between opportunistic lumbar spine CT scan and DEXA Scan in the Assessment of Osteoporosis. J Spine. 2019;8:434
26. Pickhardt PJ, Pooler BD, Lauder T, del Rio AM, Bruce RJ, Binkley N. Opportunistic screening for osteoporosis using abdominal computed tomography scans obtained for other indications. Ann Int Med 2013;158(8):588–95.
27. Bauman WA, Schwartz E, Song ISY, Kirshblum S, Cirnigliaro C, Morrison N, Spungen AM. Dual-energy X-ray absorptiometry overestimates bone mineral density of the lumbar spine in persons with spinal cord injury. Spinal Cord. 2009;47:628-33
28. Booz C, Hofmann PC, Sedlmair M, Flohr TG, Schimdt B, D"Angelo T, et al. Evaluation of bone mineral density of the lumbar spine using a novel phantomless dual-energy CT post-processing algorithm in comparison with dual-energy X-ray absorptiometry. Eur Radiol Exp. 2017;1:11.
29. Zhang RJ, Li HM, Gao H, Jia CY, Xing T, Shen CL. Associations between the hounsfield unit values of different trajectories and bone mineral density of vertebrae: cortical bone and traditional trajectories. Am J Transl Res. 2020;12(7):3906-16
30. Graffy PM, Lee SJ, Ziemlewicz TJ, Pickhardt PJ. Prevalence of Vertebral Compression Fractures on Routine CT Scans According to L1 Trabecular Attenuation: Determining Relevant Thresholds for Opportunistic Osteoporosis Screening. AJR Am J Roentgenol. 2017;209(3):491-6.
31. Hendrickson NR, Pickhardt PJ, Del Rio AM, Rosas HG, Anderson PA. Bone Mineral Density T-Scores Derived from CT Attenuation Numbers (Hounsfield Units): Clinical Utility and Correlation with Dual-energy X-ray Absorptiometry. Iowa Orthop J. 2018;38:25-31
32. Ebeling PR. Clinical practice. Osteoporosis in men. N Engl J Med. 2008; 358:1474–82
33. Schuit SC, van der Klift M, Weel AE, de Laet CE, Burger H, Seeman E, et al. Fracture incidence and association with bone mineral density in elderly men and women: the Rotterdam Study. Bone. 2004; 34:195–202
34. Liu CC, Theodorou DJ, Theodorou SJ, Andre MP, Sartoris DJ, Szollar SM et al. Quantitative computed tomography in the evaluation of spinal osteoporosis following spinal cord injury. Osteoporos Inter 2000; 11: 889–896
35. Islamian JP, Garoosi I, Fard KA, Abdollahi MR: Comparison between the MDCT and the DXA scanners in the evaluation of BMD in the lumbar spine densitometry. Egypt J Radiol Nucl Med. 2016, 47:961-967
36. Yu W, Gluer C-C, Grampp S, Jergas M, Fuerst T, Wu CY, et al. Spinal bonemineral assessment in post menopausal women: a comparison between dual X-ray absorptiometry and quantitative computed tomography. Osteoporos Int 1995;5:433439.

ISSN (O): 2687-5365; ISSN (P): 2753-6556