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Regional Differences of Hounsfield Unit in the Diagnosis of Bone Mineral Density Disease

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Abstract

In Computed Tomography (CT) the selection criteria for Hounsfield unit (HU) at vertebral body (VB) for the diagnosis of bone mineral density (BMD) disease are variable. The purpose of our study is to determine the correlation between T-score from a dual-energy X-ray absorptiometry (DXA) scan and HU values at different ROIs across the VB at L1 to L4 for the assessment of BMD disease. 114 women who had both a CT scan abdomen and DXA scan within one year were enrolled in the study. Different ROIs for HU measurements were obtained throughout L1 to L4, the lowest HU, HU at central portion of the VB; and the average of 3HU values across the VB. Statistical analysis was used to compare the performance of the different HU values for the diagnosis of BMD disease, and the correlations with the T-score. There was a moderate correlation between the T-score and HU value at different ROIs, (r 0.597, 0.615, 0.591) (P value<0.001). HU with 95% sensitivity for diagnosis of osteoporosis were 116, 123, 130 and 95% specificity were 173, 177, 181 for the lowest, central and the average of three axial slices, respectively. No statistical difference in the mean HU at L1 from the average mean of L1–L4. In conclusion the homogenous HU distribution across the VB throughout the lumbar spine and L1 will allow more flexibility in the selection of the ROI for HU values for BMD disease.

Keywords: BMD; Hounsfield unit; CT; DXA; T-score

Abbreviations: CT: Computed Tomography; HU: Hounsfield Unit; VB: Vertebral Body; BMD: Bone Mineral Density; DXA: Dual Energy X-ray Absorptiometry; ROI: Region of Interest; LS: Lumbar Spine; ROC: Receiver Operating Characteristic Curve

Introduction

Quantitative CT (QCT) is a well-known technique used to assess bone mineral density (BMD). It is based on the acquisition of volumetric data, which requires the use of controlled software and an external reference calibration phantom to decrease scan-to-scan and scanner-to-scanner variability [1]. With the standardized software and optimized technical parameters, long-term precision is 2–4% with 60 msv radiation exposure [1,2]. The long QCT scan time, relatively high radiation, and the wide introduction of dual-energy x-ray absorptiometry (DXA) scanners have limited the clinical utilization of QCT [3]. There is an interest among health workers to utilize BMD data available from the CT study in the form of the Hounsfield unit (HU) for the diagnosis of BMD disease [4]. However, there is a large variability in the selection criteria for the best region of interest (ROI) for HU values at the vertebral body (VB) as a measurement of BMD. Some studies suggest the selection of the lowest HU value across the VB in contrast to the DXA scan, which utilizes the lowest T-score at the lumbar spine or femoral head as a measurement of BMD [4]. Other researchers suggest the use of the average of HUs at 3 separate ROIs—central, superior to inferior end plate, and inferior to superior end plate of the VB—as an accurate measurement of BMD [5]. Some data concentrate on the HU value at L1–L2 as a reference measurement of CT BMD [6].

The purpose of our study is to determine the best correlation between T-scores obtained from a DXA scan and HU values obtained at different ROIs across the VB at L1–L4 lumbar spine for the assessment of BMD. The sensitivity and specificity of the HU values at each subgroup were assessed for the diagnosis of BMD disease. The performance of the HU at a single vertebra (L1), in comparison to total L1–L4, was also evaluated.

Materials and Methods

Patients cohort

We retrospectively reviewed 114 consecutive women who had both a DXA scan and a CT scan in which the lumbar spine is visualized less than one year apart between 2010 and 2014 at King Abdulaziz University Hospital. A CT scan of the abdomen and pelvis, a lower limb angiogram, and lumbar and thoracolumbar computed tomography were included in the study. Patients who had previous spine surgeries with spinal instrumentation, implantation, lumbar compressed fracture, or vertebroplasty were excluded from the study. Patients with significant degenerative disease were also excluded as DXA results would not be valid for comparison. Eighteen patients (15%) with mild degenerative disease were included in the study. Our review included approximately 2,000 patients; with 114 patients meeting the inclusion criteria. Approval from the research ethics committee was obtained.

Dual-energy X-Ray absorptiometry

Dual-energy x-ray absorptiometry of the lumbar spine from the first through fourth lumbar vertebrae and proximal femora was performed using standard techniques. The WHO classification of BMD was used [7]. Patients were categorized as having osteoporosis (T-score ≤ −2.5), osteopenia (T-score between −1.0 and −2.5), or normal BMD (T-score ≥ −1.0) using the lowest reported T-score. The lowest T-score in the lumbar spine or femoral head was selected for the diagnosis of BMD disease.

Computed tomography

Computed Tomography (CT) was done using multidetector CT scanners. We retrospectively assessed the CT images and evaluated

vertebral BMD on a standard radiology picture archiving and communication system workstation. The images were viewed in bone windows (window width=3000, window level=700). Different ROIs for HU measurements were obtained at each VB throughout L1–L4 (Figure 1): 1) ROI at the lowest HU measurement across the VB; 2) ROI at the middle or central portion of the VB; and 3) the average of HU measurements at 3 locations within the VB—immediately inferior to the superior end plate, in the middle of the VB, and superior to the inferior end plate -protocol described by Schreiber et al. [5] and Lee et al. [8]. The largest possible round ROI was drawn on the axial images at L1–L4, excluding the cortical margins to prevent volume averaging.

Statistical analysis

One-way analysis of variance (ANOVA) was used to compare the mean HU values in the three ROIs, and Pearson Correlation was used to assess the correlations of the T-scores and HUs at different ROIs. The 95% sensitivity and specificity of the HU at each ROI for the diagnosis of BMD disease were also evaluated.

Result

The mean age of the 114 patients was 58.2 ± 10, and the mean age for menopause was 40.4 ± 18.8 years. The mean average time between the CT scan and DXA scan was 68 days ± 2.43% of the patients received IV contrast. Most of the CT scans were performed for metastatic workup (70%), while 10% were performed for investigation of abdominal pain and 20% for renal disease and other causes.

Twenty-six patients (22.8%) had normal BMD with a T-score of greater than -1; 50 patients (43.9%) had a T-score less than -1 and greater than -2.5, consistent with osteopenia; and 38 patients (22.8%) were diagnosed with osteoporosis with a T-score of less than -2.5, according to a DXA scan. The mean DXA T-score was -1.91 ± 1.26 (range -5.4 to -1.1). The mean HU values across L1–L4 for the three study groups with different ROIs) are 197.8 ± 49.7 for a normal T-score, 159.1 ± 46.7 for osteopenia and 118.6 ± 52.6 for the osteoporosis group as measured by a DXA score. The mean BMD value as measured by DXA scan was 0.885 ± 0.15 g/cm^2 (Table 1).

The mean HU values for patients within the osteoporotic group according to a DXA scan were 107.82, 117.5, and 118.64; the mean HU values for a normal DXA scan were 184.57, 202.19, and 197.81 for the lowest, central, and average of the three slices across VB at L1–L4, respectively. Figure 2 demonstrates a moderate correlation between the T-score and the HU value at different ROIs. The correlation coefficients(r) throughout L1–L4 were 0.597, 0.615, and 0.591 for the lowest, central, and average HU values at the three slices across the VB. All correlations were statistically significant with a P value less than 0.001. The difference in the mean HUs at different ROIs for patients within the osteoporosis, osteopenia, and normal BMD groups was not statistically significant (P 0.39, 0.245, 0.608) (Table 2).

Under the receiver operating characteristic curve (ROC), the HU cutoff points for diagnosis of osteoporosis (95% sensitivity) were 116, 123, and 130 with 95% specificity of 173, 177, and 181 for the lowest, central, and the average of three slices, respectively. The HU 95% sensitivity values for normal BMD were 137, 152, and 145 with 95% specificity of 152, 174, and 169 for the lowest, central, and average of three slices, respectively. No significant difference was noted in the performance of HU at different ROIs for the diagnosis of normal and osteoporotic patients (Figure 3 and Table 3).

The HU values at each VB were analyzed against the average HU at L1–L4 to assess the feasibility of utilizing the HU of a single vertebral body—mainly L1—for BMD assessment (Table 4). The mean HU values

Table 1: Demographic Characteristics of Patients with Abdominal Computed Tomography and Dual-Energy X-Ray Absorptiometry Scans for Assessment of Bone Mineral Density Disease. Data reported as number (%) unless otherwise stated.

Characteristic	Value
Total number of patients	114
Age (y)	58 ± 10
Height (cm)	153.3 ± 7.11
Weight (kg)	72.1 ± 14.1
BMI	30.4 ± 5.8
Mean ± SD Hounsfield unit at L1–L4	157 ± 57
Mean ± SD T-score at DXA	0.191 ± 1.26
Number of patients with normal T-score (<-1)	26 (33.3)
Number of patients with osteopenia T-score (>1)	50 (43.9)
Number of patients with osteoporosis T-score>-2.5	38 (22.8)

Table 2: Comparison of mean HU at different ROIs and the T-score classification in DXA using one-way ANOVA.

T-score Classification	Normal	Osteopenia	Osteoporosis
HU at L1-L4			
Average of 3 slices	197.81 ± 49.71	159.04 ± 46.70	118.6 ±52.59
Lowest HU of VB	184.56 ± 47.01	145.33 ± 43.57	107.82 ± 51.09
Central HU of VB	202.19± 48.26	158.64 ± 48.39	117.50 ± 51.83
P Value	0.396	0.245	0.608

ROI: Region of Interest; SD: Standard Deviation; HU: Hounsfield Unit; VB: Vertebral Body.

Table 3: 95% Sensitivity and Specificity of mean HU at different ROIs at L1–L4 for diagnosis of osteoporosis and normal BMD.

HU at L1-L4	Osteoporosis		Normal	
	95% Sensitivity	95% Specificity	95% Sensitivity	95% Specificity
HU of 3 slices	≤ 130	≤ 181	≤ 145	≤ 169
Lowest HU	≤ 116	≤ 173	≤ 137	≤ 152
Central HU	≤ 123	≤ 177	≤ 152	≤ 174

Table 4: Mean HU at each vertebral body of L1–L4.

L1 – L4	HU value					
	N	Mean	SD	Max	Min	P Value*
L1	114	147.87	54.58	348	32	
L2	114	141.68	56.12	325	21	
L3	114	138.75	56.10	342	14	**0.739**
L4	114	138.97	57.35	350	24	
Average (L1–L4)	114	141.78	54.61	341.25	22.75	

N: sample size; SD: Standard Deviation; Max: Maximum; Min: Minimum; HU: Attenuation coefficient.
*P value was calculated using one-way ANOVA.

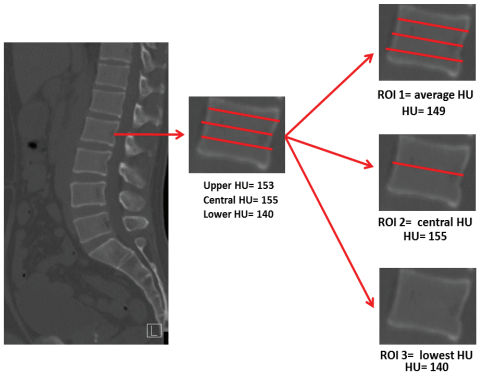

Figure 1: The different ROIs selected for HU at each lumbar vertebra. ROI 1 is the average HU of the 3 axial slices; ROI 2 is the central HU measurement; ROI 3 is the lowest HU among the 3 slices.

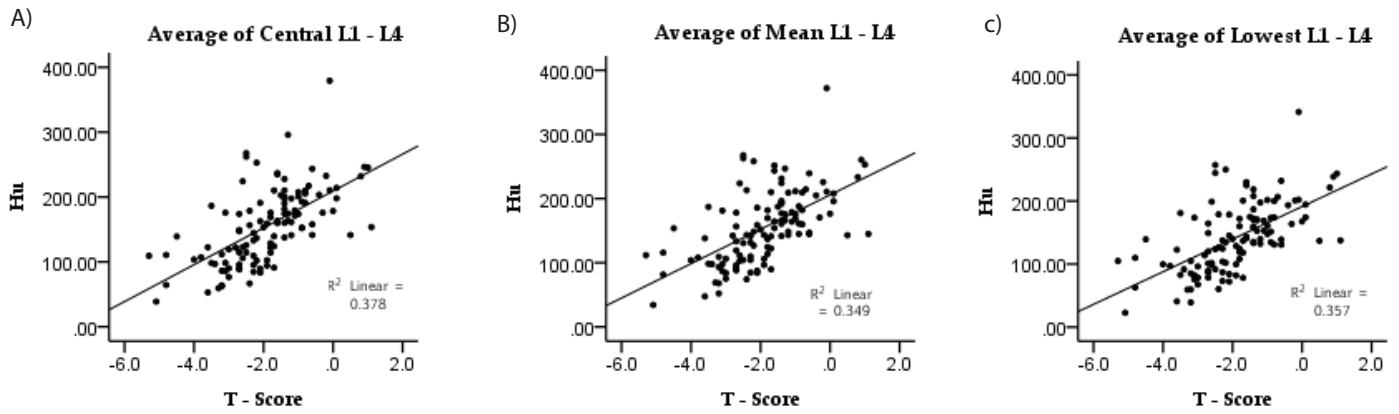

Figure 2: Correlation between T-score and attenuation coefficient (HU) at different regions of interest (ROIs) across L1–L4.Moderate correlation is noted by using Pearson Correlation. Correlation coefficient(r) at A) Central ROI is 0.615, B) Mean average of 3ROIs is 0.591, and C) ROI with the lowest HU 0.597. P Value was <0.001 at all different ROIs across L1-L4.

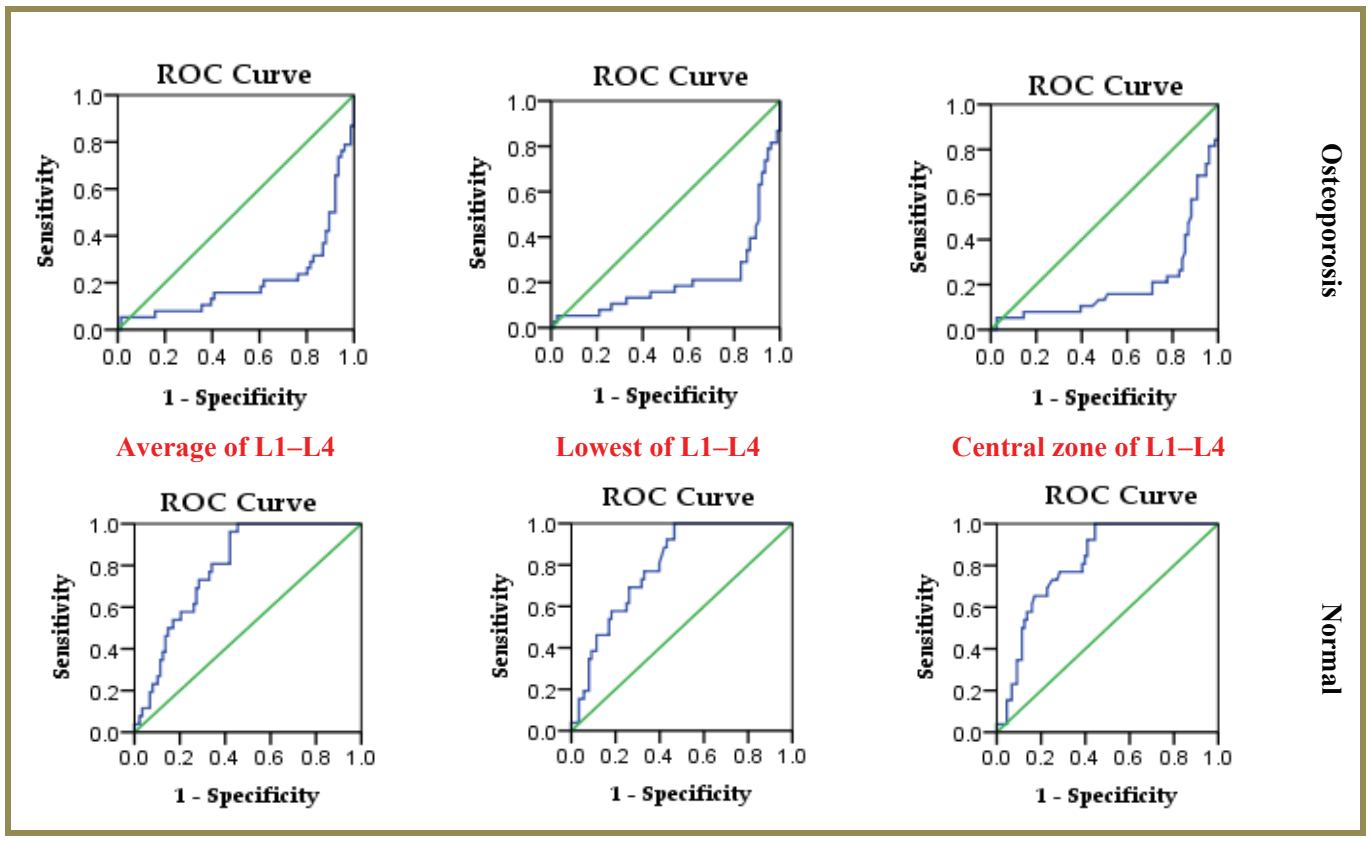

Figure 3: Receiver Operator Curve (ROC): cutoff point for diagnosis of osteoporosis and normal BMD for HU obtained at different ROIs across L1–L4.

at the lumbar spine were homogenous with no statistical difference in the mean HU across L1–L4, and no difference in the mean HU at the upper and lower lumbar spine (P 0.739). A mild decrease in the HU at L3–L4 was noted; however, it is not statistically significant (Table 4).

Discussion and Conclusion

The current study demonstrates homogenous HU distribution throughout L1–L4 at different ROIs across the VB, with a moderate correlation between T-scores from a DXA scan and HUs at different ROIs for BMD evaluation (Figure 2).

Comparable performance of HU at different ROIs across the VB (central HU, lowest HU, and HU at three axial slices) was noted with no significant difference in the mean HU, the correlation of the HU to the T-score of DXA scan, or the HU cutoff point for the diagnosis of osteoporosis, osteopenia, or normal BMD (Figures 2,3 and Table 2). The mean HU values for diagnosis of osteoporosis with 95% sensitivity are 116, 123, and 130 with 95% specificity of 173, 177, and 181 at the different ROIs (Table 3).

In a large study of 1,867 patients, the lowest HU values across VBs were selected for BMD assessment. Osteoporosis was detected at an HU range

of 110–160, and the 90% sensitivity and specificity for osteoporosis was 160 and 100, respectively [4]. In one study of 128 patients, researchers recorded the lowest HU value across VBs, where they found a mean HU for osteoporosis of 54 ± 25 (95% confidence interval CI 149-60) and an HU for normal BMD at 120.8 (95% CI 111.7-130) [9].

In another study in which researchers selected the average HU of three axial slices, a significant correlation was demonstrated between HU values and T-scores from a DXA scan; the mean HU of osteoporosis was 78.5 ± 32 (95% CI 61-95), while the mean HU for normal BMD 133 ± 37 (95% CI 118-147) [5].

In order to maximize the utilization of HU for BMD assessment, specific attention has been paid to the HU at a single vertebral body—mainly L1—which could be identified at different CT examinations including CT chest, abdomen, and lumbar spine. In our study, the mean HU value at L1 was 147.87, and the average of L1–L4 was 141.78 with no significant difference and a P value of 0.739 (Table 4). Our data at L1 is comparable to other studies concentrated on the L1 vertebra [4,9]. Other data reported higher BMD in the thoracic spine in comparison to the lumbar spine [10], and in the upper lumbar spine as compared to the lower lumbar spine [11], which could be related to IV contrast or hormones or chemotherapy.

In conclusion, there is a moderate correlation between lumbar HU values and T-scores in DXA scans for the diagnosis of BMD disease. The homogenous distribution of HU across the VB yields a comparable performance for HU at different ROIs for BMD assessment. This will allow more flexibility in the selection of HU for BMD disease. No difference was noted in the mean HU at L1 from the average mean HU across L1–L4, which will make it more feasible to use HU at a single VB and allow more available CT studies for BMD assessment (CT chest, abdomen, and lumbar spine). A prospective study with a larger number of patients is recommended. The limitations of our study include the retrospective nature of the study and the small number of patients which could affect the statistical power of the study. In the literature no similar study were found that compares HU values at different region of interest for BMD measurement.

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Conflict of Interest

None.

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