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Research Paper

Correlation Between Bone Density Measured by Routine BMD and Hounsfield Units Assessed on Diagnostic CT-scan: A Cross-sectional Study

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ABSTRACT

Background: Previous studies have shown a moderate correlation between bone mineral density (BMD) measured by dual-energy x-ray absorptiometry (DEXA) and Hounsfield units (HU) assessed on diagnostic computed tomography (CT) scans in the lumbar spine.

Objectives: In this study, we aimed to evaluate the correlation between DEXA scores and HU values for different bones and several anatomical landmarks.

Methods: In this retrospective study, 214 patients underwent DEXA and diagnostic CT scans of different bones, including the proximal humerus (n=96), distal tibia (n=56), distal femur (n=34), and proximal tibia (n=28). HU values of five anatomic landmarks, including the medulla, anteromedial cortex, anterolateral cortex, posteromedial cortex, and posterolateral cortex, were measured, and their correlation with the lowest T-score of the patients was assessed.

Results: The HU of the center of the medulla was significantly correlated with the lowest T-score in the proximal (r=0.486, P=0.04) and distal tibia (r=0.458, P=0.01). In the proximal humerus, the HU of the anteromedial cortex was significantly correlated with the lowest T-score (r=0.0353, P=0.01). The mean HU of the posterolateral cortex in the proximal humerus was significantly smaller in the osteoporotic patients (P=0.003). The mean HU of the center of the medulla in the proximal tibia was significantly lower in patients with osteoporotic (P=0.036). The mean HU values of the posteromedial cortex and center of the medulla in the distal tibia were significantly larger in patients with normal BMD (P=0.04 both).

Conclusion: A moderately significant correlation is observed between the lowest T-score and specific anatomical landmarks of the different bones.

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Introduction

Osteoporosis is a systemic skeletal disorder characterized by low bone density and destruction of bone microarchitecture, resulting in increased bone fragility [1]. The global prevalence of osteoporosis is 23.1% in women and 11.7% in men [2]. Along with the continuous increase in population aging, the number of patients living with osteoporosis has also increased; therefore, the age-standardized prevalence of osteoporosis in Iran has been reported to be 62.7% in women and 24.6% in men [3]. A higher prevalence of osteoporosis is associated with a higher incidence of fragility fractures and greater social, health, and economic burdens [4].

Currently, dual-energy x-ray absorptiometry (DEXA) is considered the gold standard for determining bone mineral density (BMD) [5]. However, the use of DEXA to determine BMD is limited. The accuracy of DEXA can be impaired by various factors, such as spine osteoarthritis [6]. In addition, the BMD of obese patients with osteoporotic can be classified as normal using DEXA [7]. Therefore, identifying alternative modalities for DEXA has always been a concern for researchers in this field.

In recent years, there has been growing interest in the use of alternative imaging techniques, such as computed tomography (CT) and magnetic resonance imaging (MRI) [8]. CT was first proposed to measure bone density in the mid-70s [9]. Despite its initial accuracy, a high dose of ionizing radiation is a primary concern for the clinical implication of CT in routine BMD assessment [9]. Even so, a CT scan can still be used to assess BMD in patients who already have a CT scan for other purposes, such as fracture diagnosis.

In this study, we evaluated the correlation between bone density obtained using DEXA (T-score) and CT (Hounsfield units [HU]) in patients for whom a CT scan had already been performed for diagnostic purposes. We hypothesized that if there is a significant correlation between the bone density assessed by CT and DEXA, the available CT scans of the patients can be used to determine the bone density, thereby exposing the patient to less radiation and reducing the cost of the patient's medical services.

Methods

The review board approved this cross-sectional study of our institute. The Ethical Committee of Iran University of Medical Sciences waived the requirement for informed consent to participate as this was a retrospective study. The medical profiles of patients referred to the fracture liaison service (FLS) of our institute between 2019 and 2023 were retrospectively reviewed. The inclusion criteria included available CT scan of the proximal humerus, distal femur or proximal tibia, distal tibia, available DEXA scan for three regions of interest (spine, femoral neck, and distal radius), and a maximum interval of one year between the date of DEXA and CT performance. The exclusion criteria included patients with a fracture on the CT scan used for HU measurements. A total of 214 patients who met the study criteria were included in the analysis.

DEXA

BMD of the spine (L1-L4), femoral neck, and distal radius was evaluated using a DEXA device (Hologic Inc., Bedford, MA, USA). BMD was expressed as mg/cm^2 and T-score. A T-score >-1 was considered normal bone density, a T-score between -1 and -2.5, osteopenia, and a T-score <2.5 was considered osteoporosis [10]. The lowest T-score was used for the analysis.

Quantitative CT scanning

All CT scans were obtained using a 128-channel helical CT scanner (Ingenuity; Phillips Healthcare, Best, Netherlands). Bone density was evaluated at five points: Anteromedial, anterolateral, posteromedial, posterolateral, and center of the medulla. The mediolateral and anteroposterior lines' intersection was considered the medulla's center. The HU was assessed three times at each anatomic point, and the average value was used in the analysis. The picture archiving and communication system (PACS; GE Digital Healthcare Inc., Chicago, Illinois) was used to calculate the HU values. To this end, an elliptical region with a diameter of 1 mm was placed over the area of interest [11]. To reduce heterogeneity, landmarks were defined for each anatomical location. For the proximal humerus, we went from the proximal to distal sections in the axial CT scan, and the first axial cut, in which the humeral head was no longer visible, was used to evaluate bone density. For the distal femur, we went from the distal to proximal sections in the axial CT scans, and the first axial cut, in which the femoral condyle was not observable, was used to evaluate bone density (Figure 1). For the proximal tibia, we went from the distal to the proximal sections in the axial CT scans, and the first axial cut in which the tibial tubercle was not identified was used for bone density evaluation. For the distal tibia, an axial CT section 2.5 cm above the distal tibial joint was used to evaluate bone density.

Sample size and statistical analysis

Choi et al. reported a correlation of 0.447 between the T-score and HU values of the entire spine [12]. Based on this correlation, an effect size of 0.07, a power of 95%, and a type 1 error of 0.05, 20 patients were sufficient to conduct this correlation study using the G*Power software. To increase the power of the study, we included all patients referred to our center during the study period.

Statistical data analysis was conducted using SPSS software for Windows, version 16 (SPSS Inc., Chicago, Ill., USA). Descriptive statistics were demonstrated as Mean±SD for quantitative variables or numbers with percentages for qualitative variables. One-way analysis of variance (ANOVA) or its nonparametric counterpart (Kruskal-Wallis test) was used to compare the mean values between different groups. Pearson or Spearman correlation coefficients were used to evaluate the potential correlations between CT and DEXA evaluations. A $P<0.05$ was considered statistically significant.

Results

The study population included 56 men and 158 women, with a mean age of 63.5±10 years (range: 51-90 years). The mean lowest T-score of the patients was -3.1±1.3. Accordingly, most of the included patients were osteoporotic (136 of 214). The most common location on CT was the proximal humerus (96 or 214). Table 1 presents the patient characteristics.

The relationship between the lowest T-score and HU of the proximal tibia

In the proximal tibia, the HU of the center of the medulla was significantly correlated with the lowest T-score of the patients (P=0.04). The HU values of other landmarks were not significantly correlated with the T-score (Table 2). The mean HU of the center of the medulla was significantly smaller in the osteoporotic patients (P=0.036) (Table 3).

The relationship between the lowest T-score and HU of the distal femur

In the distal femur, the HU of the non-anatomic landmark was significantly correlated with the lowest T-score of the patients (Table 4). The mean HU of the center of the medulla was not significantly different between the osteopenic and osteoporotic groups (Table 5).

The relationship between the lowest T-score and HU of the proximal humerus

In the proximal humerus, the HU of the anteromedial cortex was significantly correlated with the lowest T-score of the patients (P=0.01). The HU values of other landmarks were not significantly correlated with the T-score (Table 6). The mean HU of the posterolateral cortex was significantly smaller in the osteoporotic patients (P=0.003) (Table 7).

Table 1. Characteristic features of included patients

Variables		Mean±SD/ No. (%)
Age (y)		63.5±1
Sex	Male	56(21.2)
	Female	158(73.8)
The lowest T-score of the three region		-3.1±1.3
Bone status according to T-score	Normal	6(2.8)
	Osteopenia	72(33.6)
	Osteoporosis	136(63.6)
CT location	Proximal humerus	96(44.9)
	Distal femur	34(15.9)
	Proximal tibia	28(13.1)
	Distal tibia	56(26.2)

CT: Computed tomography.

Table 2. The correlation between the lowest T-score and the HU of the different anatomic landmarks in the proximal tibia

Anatomic Landmark	No.	Minimum	Maximum	Mean±SD	r, P
Anteromedial cortex	28	266	1466	595.9±296	-0.072, 0.8
Anterolateral cortex	28	326	1002	698.3±24	0.025,0.93
Posterolateral cortex	28	222	1368	784±342	0.263,0.36
Posteromedial cortex	28	315	1237	822±348	0.192,0.51
Center of medulla	28	-70	136	30.7±47.4	0.486, 0.04

HU: Hounsfield unit; r: Correlation coefficient.

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The relationship between the lowest T-score and HU of the distal tibia

In the distal tibia, the HU of the center of the medulla was significantly correlated with the lowest T-score of the patients (P=0.01). The HU values of other landmarks were not significantly correlated with the T-score (Table 8). The mean HU of the posteromedial cortex and center of the medulla were significantly larger in patients with normal BMD (Table 9).

Discussion

This study evaluated the correlation between bone density obtained from DEXA (T-score) and HU values measured from diagnostic CT images. We calculated the HU at five different anatomical landmarks (four cortices and one medulla) of four different bones, including the distal tibia, proximal humerus, distal femur, and proximal tibia. The HU of the center of the medulla was significantly correlated with the lowest T-score in the proximal and distal tibia. In the proximal humerus, the HU value of the anteromedial cortex significantly correlated with the lowest T-score. The mean HU value of the posterolateral cortex in the proximal humerus was significantly lower in patients with osteoporosis. The mean HU value of the center of the medulla in the proximal tibia was significantly lower in patients with osteoporosis. The mean HU of the posteromedial cortex and center of the medulla in the distal tibia were significantly larger in patients with normal BMD.

The correlation between bone densitometry results was assessed using DEXA and CT scans and has been investigated in several earlier studies. In 2011, Schreiber et al., for the first time, introduced HU as a tool for determining bone density on conventional CT scans without exposing patients to the high radiation dose used in

Table 3. The relationship between of HU of the different anatomic landmarks in the proximal tibia and bone status based on the T-score

Anatomic Landmark	Bone Status	Mean±SD	P
Anteromedial cortex	Osteopenia	445.6±59	0.16
	Osteoporosis	679.4±344	
Anterolateral cortex	Osteopenia	695.2±274	0.97
	Osteoporosis	700.1±237	
Posterolateral cortex	Osteopenia	863.8±272	0.53
	Osteoporosis	739.8±383	
Posteromedial cortex	Osteopenia	893.6±344	0.58
	Osteoporosis	782.2±364.5	
Center of medulla	Osteopenia	52.4±49	0.036
	Osteoporosis	18.8±44.6	

HU: Hounsfield unit.

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Table 4. The correlation between the lowest T-score and the HU of the different anatomic landmarks in the distal femur

Anatomic Landmark	No.	Minimum	Maximum	Mean±SD	r, P
Anteromedial cortex	34	173	949	476.1±24	0.002, 0.99
Anterolateral cortex	34	212	1029	471.6±245	0.195, 0.84
Posterolateral cortex	34	410	1369	822±272	-0.053, 0.84
Posteromedial cortex	34	322	1285	659.4±28	0.149, 0.56
Center of medulla	34	-29	86	25.4±37	-0.068, 0.74

HU: Hounsfield unit; r: Correlation coefficient.

quantitative CT scans. Twenty-five patients undergoing lumbar spine DEXA and CT were included in this study. The region of interest was confined to the medullary space of the vertebral body to minimize beam hardening and volume averaging by the adjacent cortical bone. The HU values were significantly correlated with both BMD (r=0.44) and T-score (r=0.48). The mean HU was significantly higher in the normal population and lower in the osteoporotic population [13]. We evaluated HU values in the cortex and medulla in the present study. The most significant correlation was observed between the medullary HU of the proximal tibia and the lowest

Table 5. The relationship between HU of the different anatomic landmarks in the distal femur and bone status based on the T-score

Anatomic Landmark	Bone Status	Mean±SD	P
Anteromedial cortex	Osteopenia	440.8±181	0.62
	Osteoporosis	500.7±281	
Anterolateral cortex	Osteopenia	496.2±329	0.74
	Osteoporosis	454.3±184	
Posterolateral cortex	Osteopenia	876.2±25	0.51
	Osteoporosis	784±294	
Posteromedial cortex	Osteopenia	651.4±317	0.92
	Osteoporosis	665±268	
Center of medulla	Osteopenia	15.7±48	0.28
	Osteoporosis	32.3±27.5	

HU: Hounsfield unit.

Table 6. The correlation between the lowest T-score and the HU of the different anatomic landmarks in the proximal humerus

Anatomic Landmark	No.	Minimum	Maximum	Mean±SD	r, P
Anteromedial cortex	96	342	1311	875.5±22	0.353, 0.01
Anterolateral cortex	96	290	1720	982.5±279	0.212, 0.14
Posterolateral cortex	96	645	1693	1081.2±272	0.180, 0.22
Posteromedial cortex	96	394	1622	961.1±28	0.113, 0.44
Center of medulla	96	-79	161	-0.3±47	0.254, 0.081

HU: Hounsfield unit; r: Correlation coefficient.

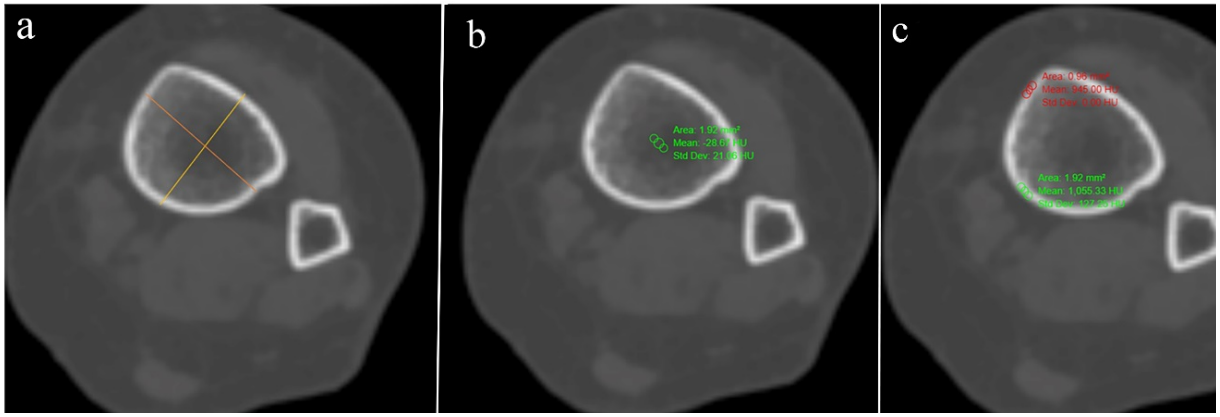

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Figure 1. a) Identification of the medulla center in the axial CT scan of the distal femour, b) Calculation of HU of the medulla center in the axial CT scan of the distal femour, c) Calculation of HU of the cortex in the axial CT scan of the distal femour
CT scan: Computed tomograpphy scan; HU: Hounsfield unit.

T-score (r=0.486). Similarly, we observed significantly higher and lower HU values in normal and osteoporotic populations.

Lee et al. evaluated the correlation between BMD measured using DEXA and HU using diagnostic CT in the lumbar spine. HU was assessed in the middle of the vertebral body but not in the cortex. The HU values were significantly smaller at higher ages (P<0.001). The HU values positively correlated significantly with the L1-4 T-score (r=0.673-0.794). The HU of the L1-4 vertebrae was considerably higher in the normal population and remarkably lower in the osteoporotic population [5]. Similar to the study by Lee et al. [5], the mean HU value of the medulla (distal tibia) was significantly higher in the normal population in the present study. Likewise, we found a significant positive correlation between the T-score and medulla HU of the proximal and distal tibia. However, the observed correlation was weaker in the present study, which can be attributed to differences in the selected bones.

The correlation between bone density was assessed using DEXA and HU measured on diagnostic CT and has also been assessed in several other studies. Ahmad et al. performed an updated systematic review of the cor-

Table 7. The relationship between the HU of the different anatomic landmarks in the proximal humerus and bone status based on the T-score

Anatomic Landmark	Bone Status	Mean±SD	P
Anteromedial cortex	Osteopenia	952.4±176	0.23
	Osteoporosis	835.8±236	
Anterolateral cortex	Osteopenia	1043.9±222	0.31
	Osteoporosis	961.3±303	
Posterolateral cortex	Osteopenia	1266.4±234	0.003
	Osteoporosis	995.7±285	
Posteromedial cortex	Osteopenia	100.9.3±272	0.39
	Osteoporosis	946.6±285	
Center of medulla	Osteopenia	6.1±34	0.18
	Osteoporosis	-13±51	

HU: Hounsfield unit.

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Table 8. The correlation between the lowest T-score and the HU of the different anatomic landmarks in the distal tibia

Anatomic Landmark	No.	Minimum	Maximum	Mean±SD	r, P
Anteromedial cortex	56	178	1218	621.1±251	0.172, 0.38
Anterolateral cortex	56	348	1524	826.3±315	0.065, 0.74
Posterolateral cortex	56	269	1368	759.2±26	0.178, 0.36
Posteromedial cortex	56	217	1232	682.1±304	0.306, 0.11
Center of medulla	56	-13	301	132±89	0.458, 0.01

HU: Hounsfield unit; r: Correlation coefficient.

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relation between BMD measured using CT and DEXA. A total of 15 CT studies were included in this review. The pooled correlation coefficients of vertebral HU versus vertebral DEXA, vertebral HU versus hip DEXA, and vertebral HU versus the lowest T-score were 0.600, 0.500, and 0.600, respectively. The correlation was weaker in the degenerative spine group. They concluded that there is only a moderate correlation between DEXA scores and HU measured on diagnostic CT. At this time, it is unclear which modality better represents bone quality. They attributed this uncertainty to inconsistencies in cohorts, imaging timing, and measurement protocols, which could be responsible for the resulting heterogeneity [14]. In the present study, for the first time, we evaluated the correlation between the T-score and HU values of different bones to determine which bone showed the most significant correlation with the lowest T-score, which was found to be the proximal tibia. Similarly, we found a moderate correlation between the T-score and HU values.

Table 9. The relationship between the HU of the different anatomic landmarks in the distal tibia and bone status based on the T-score

Anatomic Landmark	Bone Status	Mean±SD	P
Anteromedial cortex	Osteopenia	624.7±231	0.22
	Osteoporosis	587.2±236	
	Normal	912±432	
Anterolateral cortex	Osteopenia	854.1±378	0.74
	Osteoporosis	798±295	
	Normal	970.5±378	
Posterolateral cortex	Osteopenia	680.3±247	0.58
	Osteoporosis	785±272	
	Normal	843.5±253	
Posteromedial cortex	Osteopenia	567.1±184	0.04
	Osteoporosis	679.8±317	
	Normal	1161±35	
Center of medulla	Osteopenia	147.5±7	0.04
	Osteoporosis	110.8±88	
	Normal	260.5±57	

HU: Hounsfield unit.

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Conclusion

A moderate correlation was found between the HU values of different bones at different anatomical landmarks and the lowest T-score of the patients. The strongest correlation was found between the medullary HU of the proximal tibia and the lowest T-score. The mean HU at some landmarks was associated with bone status evaluated by DEXA; therefore, the medullary HU was significantly smaller in osteoporotic patients and more significant in the normal population. These findings reveal the value of HU in determining bone quality. However, further standardization is required before the clinical implications of HU can be used to assess bone quality.

The present study has some limitations. Since we included patients referred to the FLS, most patients were in the osteopenia or osteoporosis group, and the number of patients with normal BMD was minimal. All CT and DEXA images in the present study were obtained using the same scanner. Therefore, the results may not be reproducible for other CT and DEXA scanners. Finally, the HU values were calculated for the trabeculated bone (medulla) and cortical bone separately, while the DEXA values included both the cortical bone and trabeculated bone. This difference can impair the correlation strength between CT and DEXA and should be addressed in future studies.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of Iran University of Medical Sciences, Tehran, Iran (Code: IR.IUMS.FMD.REC.1402.330). The review board waived the requirement for informed consent to participate as this was a retrospective study.

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Authors' contributions

Conceptualization: Mohammad Reza Bahaeddini; Methodology: Behnam Jafari; Software, validation, and formal analysis: Hamed Tayyebi; Investigation, resources, and data curation: Masih Rikhtegar, Amir Aminian, Pouria Tabrizian, Mohammad Sadegh Mirjalily, Shayan Amiri, and Javad Khaje Mozafari; Writing, visualization, supervision, and project administration: Hamed Tayyebi.

Conflict of interest

The authors declared no conflict of interest.

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