

Correlation of Bone Mineral Density Measured in Quantitative Computed Tomography with Hounsfield Unit

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Received: July 31, 2020; **Published:** September 30, 2020

Abstract

Background: Bone mineral density scan (BMD) is a simple, non-invasive procedure used to assess the strength of the bones by measuring the composition of minerals mainly calcium in the bones. In this study, BMD was measured using Quantitative Computed Tomography (QCT) and Hounsfield unit (HU) in the lumbar spine and the values were correlated.

Methods: 240 participants referred for CT Abdomen and CT Lumbar spine were scanned using 64 slice Brilliance CT. Using BMD software, three different vertebral bodies from L1-L3 were taken and ROI was placed at the central portion of the trabecular bone. Two references ROI one in retro spinal muscle and one in fat tissue was also placed. To measure CT attenuation value an ROI graphic tool was drawn at the trabecular bone. The average of BMD in QCT and HU value was taken from L1-L3. Pearson Correlation Coefficient was used to correlate QCT and HU values.

Results: The mean BMD for the 21 - 40 age group was found to be 156.3 and 228.0 for QCT and HU respectively. Similarly, the mean BMD for 41 - 60 and 61 - 80 age groups was found to be 125.5, 173.6 and 109.1, 140.4 for QCT and HU respectively. The results showed a strong positive correlation between QCT and HU BMD ($r = 0.94$) with a p-value less than 0.001.

Discussion: In our present study, 64.53% ($n = 155$) were found to have normal BMD based on the WHO diagnostic category for spine BMD in QCT. Whereas 24.58% were found to have a low bone mass (osteopenia) and 10.83% were found to have osteoporosis. The equivalent mean HU was found to be 211.98 ± 31.06 , 139.64 ± 18.58 , 87.22 ± 15.92 for normal, osteopenia and osteoporosis respectively.

Conclusion: The study shows a strong correlation between QCT BMD with HU. Therefore, the CT attenuation technique can also be used to derive bone mineral density values from routine abdomen and lumbar spine MDCT for osteoporosis screening with no additional cost to the patient.

Keywords: BMD; Hounsfield Unit; QCT

Introduction

Osteoporosis is a skeletal disorder characterized by a low bone mass and a structural deterioration of the bone tissue [1]. A Bone Mineral Density (BMD) test can detect either osteopenia or osteoporosis and is indicated for individuals with suspected low BMD including women age 65 years and above and men older than 70 years [2]. BMD test can also be done in conditions associated with low bone mass or bone loss such as lack of estrogen, low calcium and vitamin D intake, hyperparathyroidism, malabsorption and eating disorders [2]. Bone densitometry or bone mineral density (BMD) tests can be performed in several ways. The gold standard for measuring BMD is using Dual-energy X-ray Absorptiometry (DXA) [3,4]. It is one of the safest and the radiation doses from DXA scans are low, equals to an average of one or two days' exposure to natural background radiation [5]. However, the main disadvantage of a DXA scan is that it does not differentiate between cortical and trabecular bone. The accuracy may interfere with aortic calcification, vertebral fractures and degenerative changes which typically increase the BMD value [2,5]. In such instances, CT scans may be more useful.

Quantitative Computed Tomography (QCT) is a simple, non-invasive procedure used to assess the strength of the bones by measuring the composition of minerals mainly calcium in the bones. Nowadays QCT is performed using an application which uses paraspinous muscle and fat tissue as internal reference standards [6,7]. Since the patient's muscle and fat tissue are used as references in phantomless QCT and do not normally vary from one exam to another, reproducibility errors in positioning are not a problem as they are for external phantoms [7]. QCT measures the volumetric Bone Mineral Density, expressed in units of mg/cm^3 [2]. BMD values are displayed and reported together with T-score and Z-score values from the World Health Organization (WHO) guidelines [2]. T-score is a standard deviation that calculates how much a result varies from the average or mean and compares a given patient's BMD to the mean BMD of a young, healthy individual [6]. T-score lower than -2.5 are considered to have osteoporosis whereas in osteopenia the T-score lies between -1.0 to -2.5. T-score greater than -1.0 is considered to have a normal bone mass [3]. While measuring spine BMD from QCT, WHO has suggested assigning a diagnostic category of BMD greater than $120 \text{ mg}/\text{cm}^3$ as Normal, BMD between $80 \text{ mg}/\text{cm}^3$ to $120 \text{ mg}/\text{cm}^3$ as Osteopenia and BMD less than $80 \text{ mg}/\text{cm}^3$ as Osteoporosis [2]. Z-score compares a patient's BMD to the average BMD value of their own age, gender, and race displayed in units of standard deviation [6]. Z-scores above -2.0 is within the expected range and scores lower than -2.0 are considered to have a low bone density [2]. Since QCT can measure density only in the trabecular bone it is more sensitive and accurate. The main disadvantages of QCT are the cost and the higher radiation dose.

Recent studies have shown the possibility of measuring bone mineral density by Hounsfield unit. The main advantage is that it can be measured in abdominal scans, where additional radiation exposure could be avoided [8]. Hounsfield unit (HU) is a quantitative scale used in Computed Tomography to measure radiodensity. Hounsfield unit was established by Sir Godfrey Hounsfield and was named after him. Hounsfield unit is the measurement of the linear attenuation coefficient of the tissues and is established on a relative basis with the attenuation of water as a reference. Thus, the HU unit of water is always 0, whereas bone and air are +1000 and -1000, respectively [9]. Although Hounsfield unit values are not absolute measurements of material density, the higher the CT number the denser the tissue. In this study, we investigate the correlation between the bone mineral density measured by QCT and the HU values.

Methods

The approval for this study was acquired from Institutional Research Committee (IRC SOAHS and Institutional Ethical Committee (IEC) KMC, Manipal prior to conducting the study. The study included 240 participants referred for CT Abdomen and CT Lumbar spine. In this study participants who had a vertebral fracture and generalized disease of bone (Paget's disease, bone spur, implants) were excluded. They were categorized into three age groups: Young Adult age between 21 - 40 years, Elderly Adult 41 - 60 years and Old Age 61 - 80 years. All the scans were performed on 64-slice, Philips Brilliance MDCT. The CT scan was performed in a supine position using a routine CT Abdomen or CT Lumbar spine protocol.

Technique for QCT assessment of BMD in lumbar spine

Quantitative Computed Tomography (QCT) assessment of Bone Mineral Density (BMD) was performed using Philips Bone Mineral Density application on the Extended Brilliance Workspace post-processing system version 4.0. A set of axial images was loaded. Then a circular region of interest (ROI) was placed at the central portion of the trabecular bone from L1 to L3. Two references ROIs were placed; one in retrospinal muscle and one in fat tissue. A vertebrae ROI CT number should be above 15. Muscle ROI CT number should be in the range of 40-120. The fat ROI CT number should be in the range of -150-0. Once the ROIs are placed, a histogram is created.

The histogram displays an appropriate bell curve which indicates good ROI placement as shown in figure 1.

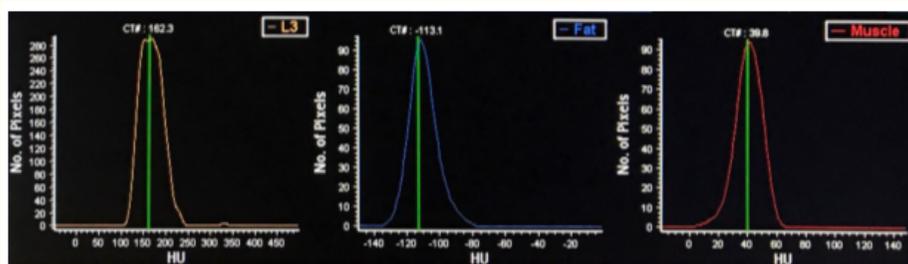


Figure 1: Histogram displaying bell curve indicates good ROI placement.

In the Results stage, the results were reviewed and it was compared with the normal population. Results obtained from a BMD study showed a Bone Mineral Density score, in units of mg/cm³. The T-score and Z-score for each vertebral body were also measured (Figure 2).

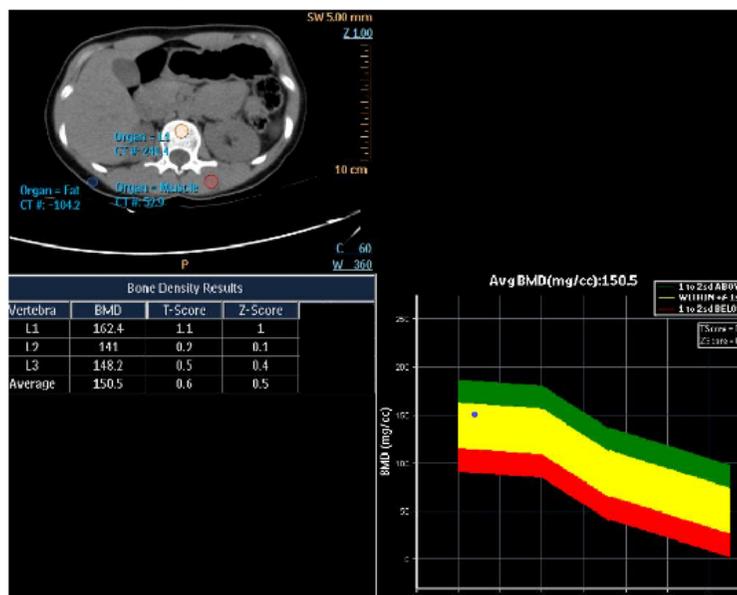


Figure 2: QCT technique for assessing Bone mineral density.

Technique for Hounsfield assessment of the lumbar spine

Vertebral Hounsfield unit (HU) measures were taken from a reconstructed cross-sectional slice. The ROI graphic tool was used to measure the CT HU value. To get an accurate value of HU, a sagittal reconstruction was used so that the transverse plane lies parallel to the end plate at each lumbar level.

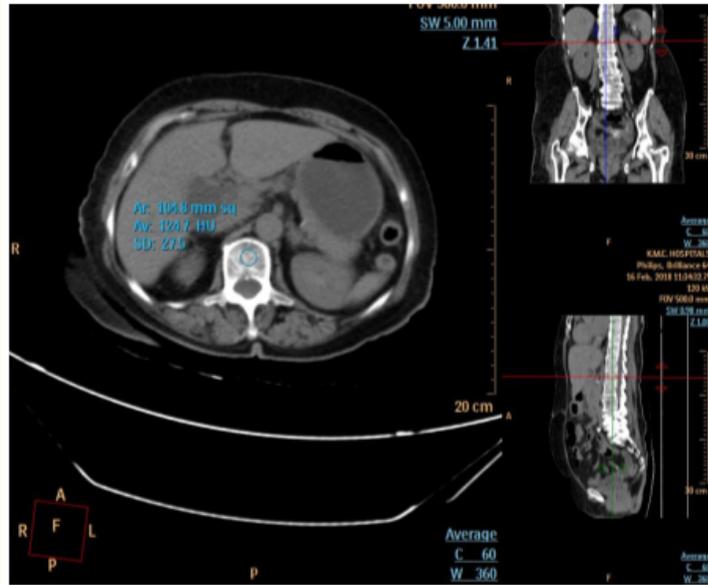


Figure 3: Technique for obtaining HU value with circular ROI placement.

HU readings were taken at the mid-body of the vertebrae by placing a circular ROI from L1 to L3. The HU value from the three vertebrae was averaged to give a mean HU. Then the mean HU was used to correlate with the BMD value of QCT.

Statistical analysis

The statistical analysis was carried out using Social Package of Statistical Science software (SPSS, version 20.0). BMD value of QCT with HU was correlated using Pearson Correlation Coefficient.

Results

The mean QCT was reported as 130.33 ± 35.77 . Mean BMD for the young adult age group was found to be 156.36 ± 19.13 . For the elderly adult and old age group, the mean BMD was 125.51 ± 27.87 and 109.13 ± 39.53 respectively. The mean HU was 180.66 ± 52.28 . For the young adult age group, the mean HU was 228.0 ± 25.78 . For the elderly adult and old age group, the mean HU was 173.60 ± 39.50 and 140.44 ± 45.66 respectively. There was a strong positive linear relationship between QCT and HU ($r = 0.94$) as shown in figure 4.

All three age groups showed a strong positive linear relationship between BMD QCT and HU. The correlation was found to be lowest for the young adult age groups ($r = 0.88$) and highest in the elderly adult age group ($r = 0.94$).

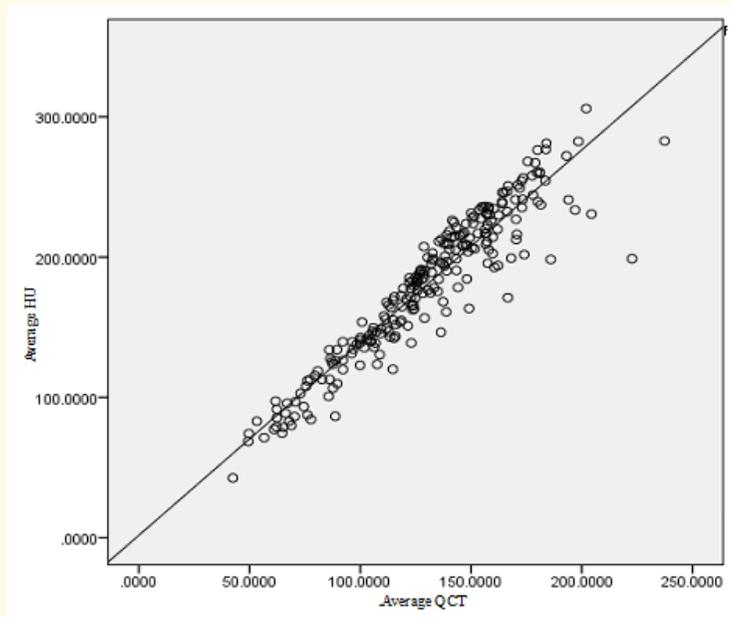


Figure 4: Scatter plot showing correlation between QCT and HU.

Discussion

Osteoporosis is the most common bone disease in humans and affects an enormous number of people, of both sexes and all races [10,11]. Osteoporosis can cause complications such as fractures but can be prevented, diagnosed, and treated before it occur [11]. Osteoporosis often goes undetected and untreated because at the early stages of osteoporosis there are no symptoms. In our study, we tried to derive bone mineral density from the Hounsfield unit for patients referred for the routine abdomen and lumbar spine CT scans, where an opportunity exists without the need for additional radiation exposure. HU measurements can be easily obtained from a CT scan and can provide valuable information about the bone density with minimal effort. In our study, we measured BMD in Quantitative Computed Tomography and correlated it with the CT attenuation technique (HU).

A study conducted by Bansal S C., *et al.* found QCT is more sensitive for diagnosing osteoporosis than DXA [12]. Several studies have shown a positive correlation between DXA and QCT or DXA with HU [8,12-17]. However, we have correlated bone mineral density by QCT with HU and found a strong positive correlation ($r = 0.94$). In our study, we have found that L1 has the highest BMD QCT for all the age groups and L3 has the lowest. A similar study conducted by Perry., *et al.* [8] showed that BMD in QCT was found to be lowest in L3. Therefore, at least two or three lumbar vertebral bodies measurement should be taken during the measurement of BMD using QCT as recommended by the American College of Radiology [2]. The mean QCT was found to be 130.33 ± 35.77 which was found to be similar to a study done by Bansal SC., *et al.* [12] where the mean QCT was 124.40 ± 50.9 . However, there was a difference in the mean BMD for QCT for different age groups.

Various studies have been conducted to set the normative value for the vertebral Hounsfield unit. However, the mean HU from our study was found to be higher when compared with data from various studies in the literature. In Schreiber., *et al.* [18] study they have included trauma patients from 20 - 80 years which was the exclusion criteria for our study. Trauma patients with severe fracture deformity

and implants are known to influence the accuracy and/or precision of the bone mineral density measurements [2]. This could be one of the reasons why our study showed a higher mean HU. Similarly, in Perry, *et al.* [8] study 252 adult’s with age ranging from 50 - 87 years were included. Whereas, in our study, we have included from 21 - 80 years (Table 1).

Level	Mean HU values		
	Schreiber, <i>et al.</i> (n = 80)	Perry, <i>et al.</i> (n = 252)	Present study (n = 240)
L1	170.5	152.9	187.2
L2	169.2	143.7	181.8
L3	166.8	130.5	172.9

Table 1: Mean HU for L1-L3 vertebra in present study with various data.

In our present study, out of 240 participants, 64.53% (n = 155) were found to have normal BMD based on the WHO diagnostic category for spine BMD in QCT. Whereas 24.58% were found to have a low bone mass (osteopenia) and 10.83% were found to have osteoporosis. The equivalent mean HU was found to be 211.98 ± 31.06, 139.64 ± 18.58, 87.22 ± 15.92 for normal, osteopenia and osteoporosis respectively (Table 2).

Classification*	QCT		HU	
	Mean	St. Deviation	Mean	St. Deviation
Normal (> 120 mg/cm ³) N = 155	151.55	21.92	211.98	31.06
Osteopenia (80 - 120 mg/cm ³) N = 59	102.97	11.20	139.64	18.58
Osteoporosis (< 80 mg/cm ³) N = 26	65.85	9.69	87.22	15.92

Table 2: Mean QCT and HU for normal, osteopenia and osteoporosis.

**Based on WHO diagnostic category for spine BMD from QCT.*

A study conducted by Sungjoon, *et al.* [15] found that a normal, osteopenic and osteoporotic bone density had a mean HU value of 120.8 ± 41.8, 78.8 ± 23.0 and 54.7 ± 25.2 respectively which was lower than the mean HU from our study. This variation in mean HU could be due to the differences in participants selected for the study as they have included only female patients aged above 40 (mean age of 66.4 years) and it is known that usually female above 45 years of age undergo menopause which can cause a decline in bone density [10]. However, a study conducted by Man Kyu, *et al.* [16] showed that the mean HU for osteoporosis, osteopenia and normal bone mass were similar to our study. Although, they have compared HU with DXA. Our study showed a strong positive correlation of BMD QCT with HU, thus the HU values could be used to provide information about the presence of osteoporosis.

We also tried to differentiate the value of BMD QCT and HU for both genders among the three age groups. Our study showed no significant difference in BMD for young adults. However, there was a significant difference in the elderly and old age groups. It could be due to the lower estrogen level in females above 45 years as they undergo menopause which lead to a decline in bone mineralization [10].

Our study has some limitations, the normative value for HU could not be set as the sample size was small since the study was time-bound. Further studies can be done for a larger sample size to establish a normative value. Secondly, clinical information about the patients was not assessed. They could be on a metabolic bone medication such as hormone replacement therapy which could elevate the HU

values. CT scans were performed using normal routine abdomen and lumbar spine protocol since the patient referred for bone mineral density is limited in our institution. However, it was later reconstructed into the recommended BMD protocol for the assessment of bone mineral density using QCT.

Conclusion

This study concluded there is a strong positive linear correlation between BMD Quantitative CT and Hounsfield unit. Therefore, the CT attenuation technique can also be used to derive bone mineral density values for osteoporosis screening from the routine abdomen and lumbar spine MDCT with no additional cost to the patient.

Funding

No funding was received for this research.

Ethics Approval and Consent to Participate

The study protocol followed was reviewed and approved by the Research Committee of School of Allied Health Sciences and Manipal Academy of Higher Education, and ethical clearance was also obtained by Kasturba Medical College and Hospital, MAHE, Manipal. A detailed explanation about the study was given by the principal investigator after which they provided consent for publication. All the patients included in this research gave written informed consent to publish the data contained within this study.

Availability of Data and Material

The data has been uploaded as supplementary files in the upload section.

Competing Interests

The authors declare that they have no competing interests in this study.

Authors' Contributions

RK conceptualized the study. RK, RL and NP have given inputs in study design. RL collected the data. RK and RL analysed the data and wrote the first draft of manuscript and all co- authors contributed in critical review of data analysis and manuscript writing. RK will act as guarantor for this paper. All authors have read and approved the manuscript.

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Volume 2 Issue 10 October 2020

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