Research Article

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Hounsfield Units on Lumbar Computed Tomography for Predicting Regional Bone Mineral Density

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Abstract: Objective: Bone mineral density (BMD) is a very important factor in spinal fusion surgery using instrumentation. Our aim was to investigate the utility of Hounsfield units (HU) obtained from preoperative lumbar computed tomography (CT) to predict osteoporosis coupling with data of quantitative computed tomography (QCT) and dual X-ray absorptiometry (DEXA).

Methods. We reviewed 180 patients that underwent both QCT and lumbar CT for spine surgery. HU was retrospectively calculated on the lumbar CT of 503 lumbar vertebrae from L1 to L3. Femur DEXA was performed in all patients and spine DEXA was tested in 120 patients (331 vertebrae). BMD was grouped as osteoporosis (QCT<80mg/cm^3, DEXA T score≤-2.5) and non-osteoporosis (QCT≥80mg/cm^3, DEXA T score>-2.5) for comparison of HU value.

Results. HU value and BMD showed significant correlations. The optima cut-off value based on QCT was higher than that of DEXA scans which had the best correlation for predicting osteoporosis. ROC curve analysis demonstrated that HU value with QCT of 146 has a sensitivity of 94.3% and a specificity of 87.5% for osteoporosis.

Conclusions: Significant correlation was found between HU measurement and BMD value. These findings provide evidence that HU measurement can be established as a means for predicting osteoporosis before spine fusion surgery with reduced radiation hazard.

Keywords: Hounsfield Unit; Bone Mineral Density (BMD); Dual X-ray absorptiometry (DEXA); Quantitative computed tomography (QCT); Osteoporosis

1 Introduction

Bone quality is an important prognostic factor for spinal fusion with instrumentation. Severe osteoporosis is a significant cause of hardware failure such as pedicle screw loosening and pull-out after spinal fusion surgery. Thus, bone mineral density (BMD) is a very important factor in spinal fusion surgery, and the diagnosis of osteoporosis before surgery is very important. BMD using dual X-ray absorptiometry (DEXA) or quantitative computed tomography (QCT) is routinely undertaken in geriatrics and suspicious osteoporosis before spinal surgery.

DEXA is commonly used as the gold standard for assessing BMD [1-3]. Based on the World Health Organization (WHO) classification, osteoporosis is defined as a T-score less than -2.5 on DEXA. However, the results of the DEXA scan can be overestimated or fail to diagnose the osteoporosis exactly when the patients have aortic calcification, severe bony spur, sclerosis and obesity [4-6].

Many studies have reported that QCT can be more sensitive for assessing osteoporosis than DEXA because QCT directly reflects the trabecular bone quality without superimposition of the cortical bone and other tissues [7-10]. However, QCT can be examined only in spine and has the limitations of high associated cost and radiation hazard. Thus, QCT is not routinely used like DEXA.

Lumbar CT is routinely performed for identification of the anatomic structures before surgery, especially in fusion surgery. The Hounsfield unit (HU) of lumbar vertebral body can easily be measured using the Picture Archiving and Communication System (PACS). Previous studies reported the relevance between HU using lumbar CT and

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BMD based on DEXA [10-13]. Significant correlation was identified between HU and BMD.

2 Materials and methods

2.1 Ethics approval

This study was approved by the Institutional Review Board of our hospital (IRB No. 1810-014-071).

Informed consent has been obtained from all individuals included in this study.

2.2 Patient population

This study reviewed data of 503 vertebrae from 180 consecutive patients who underwent QCT and lumbar CT for lumbar spine surgery between February 2016 and March 2018. All patients had undergone both QCT and DEXA scans at the same time. Spine and femur DEXA scans had been performed in all patients. Spine DEXA scans were performed in 120 patients and 331 vertebrae were analyzed in this study.

The examination period between QCT and lumbar CT did not exceed the 3-months interval. The exclusion criteria included fracture, spine tumor, rheumatic disease, spondylopathy, infectious spondylitis and lumbar instrumentation surgery. The current study consisted of 124 females (68.9%) and 56 males (31.1%), aged 20 to 95 years (mean age 68.1±10.0).

2.3 Imaging protocol

QCT scans were performed using a Philips Brilliance 16-slice multidetector helical CT scanner (GEMINI TF CT, Philips, Eindhoven, The Netherlands) to acquire the volumetric BMD (vBMD, measured in mg/cm3) at the lumbar spine from L1 to L3 vertebra. CT was used at a voltage of 120 kVp with a slice thickness of 3 mm. The CT images were processed to extract the volumetric BMD using the QCT Pro (version 4.2.3. Mindways Software, Inc., Austin, TX, USA) in conjunction with a solid-state CT calibration phantom (Model 3 QA phantom. Mindways software). Elliptical regions of interest (ROI) were automatically put in the midplane of three vertebral bodies in the trabecular bone (Figure 1).

DEXA scans were obtained with a Lunar Prodigy (General Electric, medical system) and analyzed using the Encore software (version 13.0). T-scores and area BMD (aBMD, measured in g/cm2) were obtained from L1 to L4 vertebra.

For HU measurements, all subjects were assessed using a helical 256 channel CT scanner (Revolution: GE Healthcare, Germany). The CT parameters included slice thickness of 2.5mm with 2.5mm intervals, tube voltage of 120 kVp, tube current of 150 mA with bone reconstruction settings (window width/level, -3000/300). Two-dimensional reconstruction images were acquired in the coronal and sagittal planes. The measurements of HU were obtained by two physicians independently using software PACS. The HU measurement for each vertebra was obtained by drawing the largest ROI at the mid-vertebral body excluding the cortical margin. During the HU measurements, the observers were blinded to the BMD results of QCT and DEXA scans. HU results were categorized into osteoporosis and non-osteoporosis which were compared with the value of QCT and DEXA.

2.4 Statistical analysis

The data are presented as frequency and percentage for the categorical variables, and mean±standard deviation (SD) for the numeric variables. Differences in study participants' characteristics were compared across subgroups using chi-square test or Fisher's exact test for categorical variables, and the independent test or Mann-Whitney's U test for continuous variables as appropriate. To check if its distribution was normal, we used the Shapiro-Wilk's test. The inter-observer reliability calculation was performed with the use of an interclass correlation coefficient, reported as a score between 0 and 1 (0 indicates no agreement and 1 indicates perfect agreement). A score of >0.8 is considered to indicate excellent agreement. Pearson correlation coefficients were used to assess the correlation between HU and other numeric variables. For the correlation coefficient, a score between -1 and 1 was reported (0 indicates no agreement, while 1 signifies perfect positive correlation and -1 signifies perfect negative correlation). The receiver operating characteristic (ROC) curve was used to assess the sensitivity and specificity for osteoporosis diagnosis. Positive and negative predictive HU values were calculated on the basis of the QCT and DEXA standard (Osteoporosis vs. Non-osteoporosis).

All statistical analyses were carried out using the SPSS 24.0 version and MedCalc 11.6.0 version statistical software. P values less than 0.05 were considered significant.

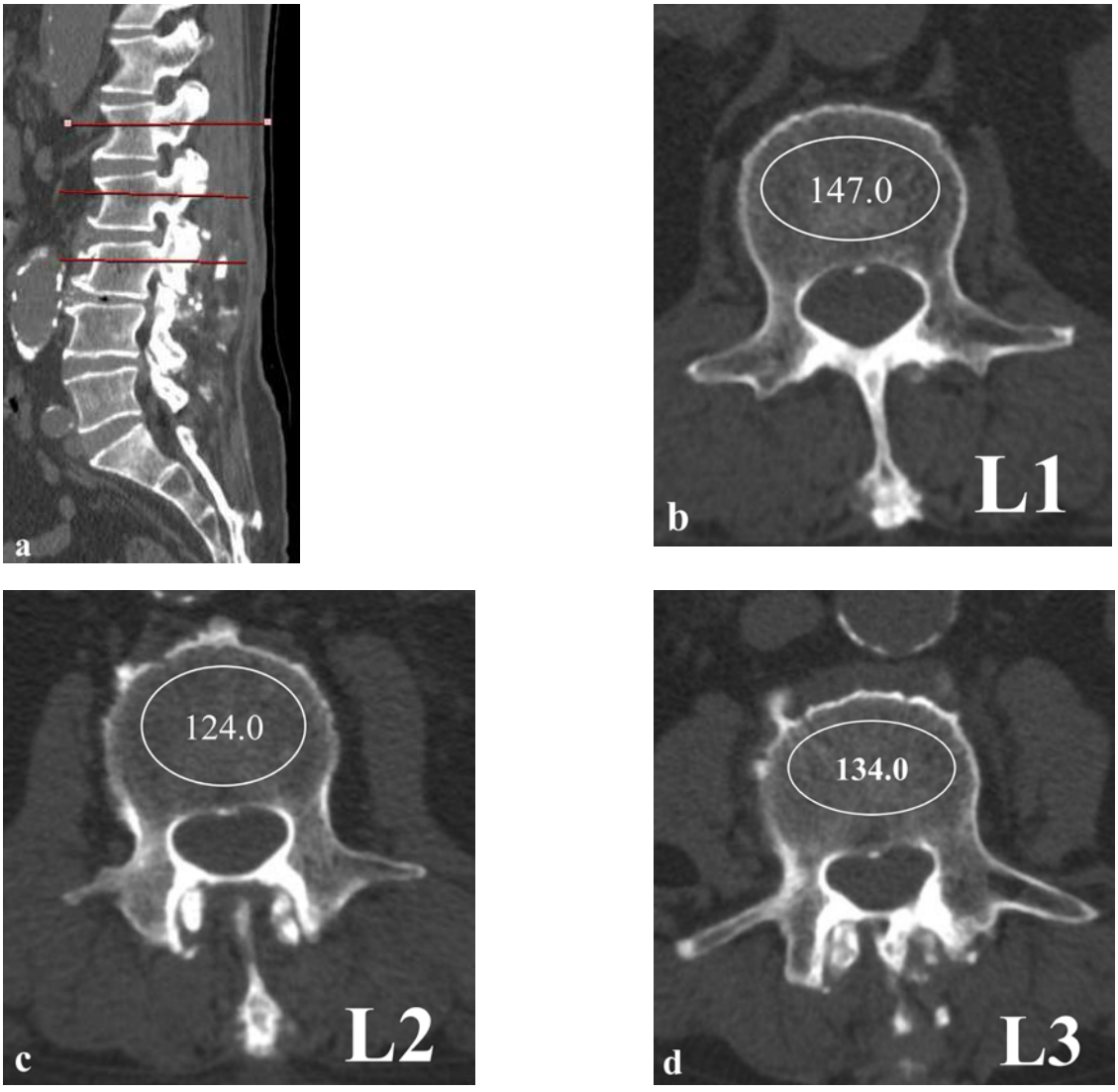


Figure 1: Hounsfield Units measurement by drawing elliptical ROI on lumbar CT scan. The largest ROI is drawn excluding the cortical bone and vascular markings at mid-vertebral body from each vertebra.

(a) Sagittal image, (b) L1 axial image, (c) L2 axial image, (d) L3 axial image

3 Results

Measurement of the HU value was reliable, with excellent inter-observer reliability of 0.961(p=.000). The HU value increased relatively linearly by QCT, and Pearson's correlation coefficient between HU and QCT at L1 through L3 was significant (r=0.868, p=0.000) (Table 1). On comparison with DEXA, QCT showed strong correlations (Figure 2).

The area under the ROC curve (AUC) value was calculated using the ROC curve to evaluate the accuracy of the HU value for prediction of osteoporosis. The optimal cut-off value for predicting osteoporosis using HU value is different depending on the comparison exam. Based on the QCT results, the optimal cut-off value was highest at 146. Spine DEXA and femur DEXA scans showed 95 and 86, respectively. The HU value was significant as a predictor of osteoporosis based on QCT (AUC = 0.960, p = 0.000) (Table 2). Sensitivity and specificity were 94.3% and 87.5%, respectively, when the optimal cut-off value was below 146 in HU-based osteoporosis prediction. Positive and negative predictive values were 97.6% and 74.5%, respectively (Figure 3). The optimal cut-off value for predicting osteoporosis of HU measurements are summarized in Table 3 by comparison exams.

Table 1: Pearson correlation coefficients (p value) of HU with imaging results.

Variables	L1	L2	L3	L1-3
HU and QCT	0.883(<0.001)	0.865(<0.001)	0.874(<0.001)	0.868(<0.001)
HU and SPINE DEXA	0.552(<0.001)	0.535(<0.001)	0.542(<0.001)	0.489(<0.001)
HU and FEMUR DEXA	0.349(<0.001)	0.469(<0.001)	0.374(<0.001)	0.393(<0.001)

Table 2: Comparison of the area under the ROC curve (AUC).

Variables	AUC	P value	UCL*	LCL*
HU and QCT	0.960	0.000	0.985	0.935
HU and SPINE DEXA	0.781	0.000	0.836	0.727
HU and FEMUR DEXA	0.767	0.000	0.808	0.726

* UCL: upper confidence limit
*LCL: lower confidence limit

Table 3: Sensitivity, specificity, and predictive values for osteoporosis/osteopenia of HU measurements by spine QCT and DEXA.

Variables	Cut-off Value	BMD		Sensitivity	Specificity	PPV*	NPV*
		Abnormal	Normal				
HU and QCT	≤ 146	399	10	94.3% (399/423)	87.5% (70/80)	97.6% (399/409)	74.5% (70/94)
	> 146	24	70				
HU and DEXA	≤ 95	94	73	82.5% (94/114)	66.4% (144/217)	56.3% (94/167)	87.8% (144/164)
	> 95	20	144				

*PPV = Positive predicted value
*NPV = Negative predicted value

4 Discussion

BMD is a very important factor to be considered in spinal fusion surgery. Osteoporosis is the major cause of surgical failure including screw loosening, proximal junctional fracture and non-union [14]. It is very important to identify the presence of osteoporosis before spine surgery. DEXA is the gold standard tool for assessing BMD [1, 2, 4, 15]. However, DEXA may show inaccurate BMD results in patients with severe degeneration, aortic calcification and obesity. In these cases, BMD can be overestimated and DEXA can demonstrate incorrect normal values despite clinical osteoporosis [16-18].

BMD can also be measured using QCT, which is a specific test with more advantages in diagnosing osteoporosis of the spine [19, 20]. However, QCT has several limitations such as applicability only in the spine, requirement of phantom calibration, high cost, and radiation hazard. Thus, QCT is not widely used in the clinical practice. Radiation exposure from CT is calculated as approximately 2.5-5 mSv, whereas that from QCT is 1.5 mSv [21]. The radiation hazard is increased when both lumbar CT and QCT are performed.

Lumbar CT is routinely performed before spine surgery for identification of bony structures. In addition, spinal surgeons can easily measure the HU of lumbar CT using the PACS system. In this study, we measured HU in the vertebral body corresponding the center of the pedicle, the most important area for spine instrumentation. In CT images, HU represents a normalized index of X-ray attenuation based on a scale of 21000 defined for air and 0 for water at standard pressure and temperature. When a voxel with an average linear attenuation coefficient (u) is

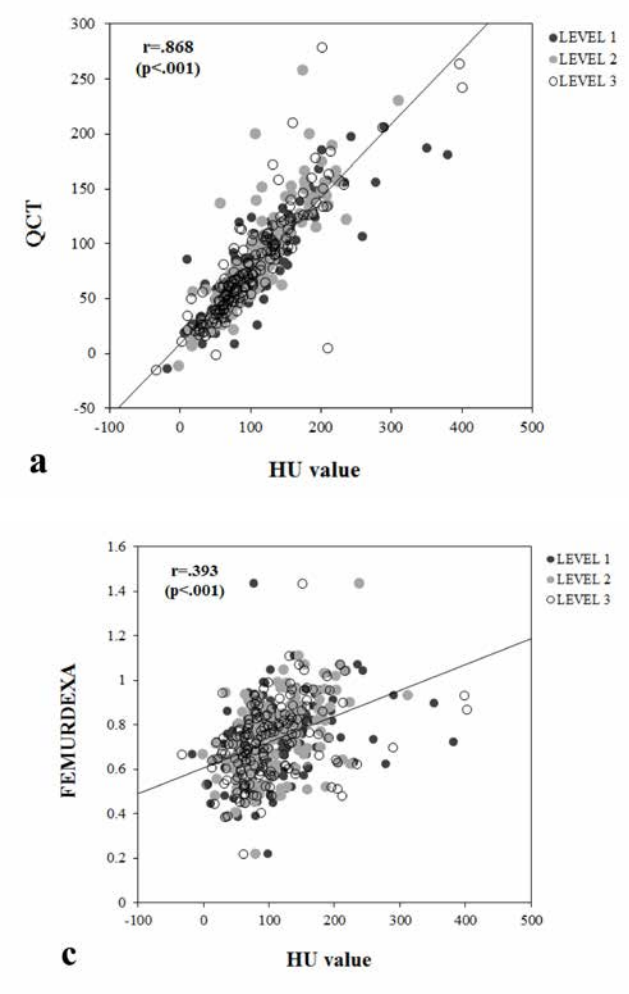


Figure 2: Scatter plots showing strongest correlations between HU and QCT (r=0.868, p=0.000).

(a) Spine QCT, (b) Spine DEXA, (c) Femur DEXA

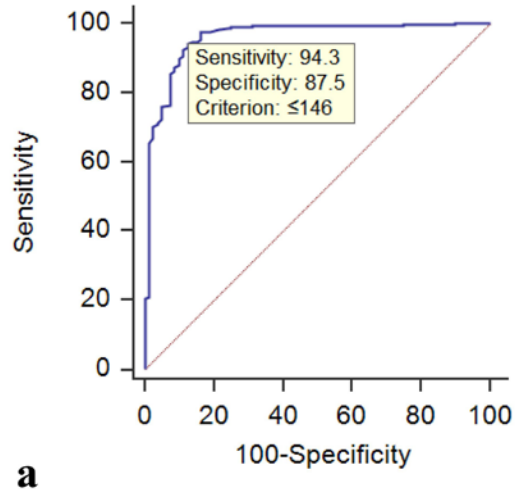
calibrated to the X-ray attenuation of water (*w*), the complete formula to calculate HU is HU = ($[u - u_w]/u_w$) * 1000, where u_w is the linear attenuation coefficient of water. The HU values for bone vary from 300 to 3000 [22, 23].

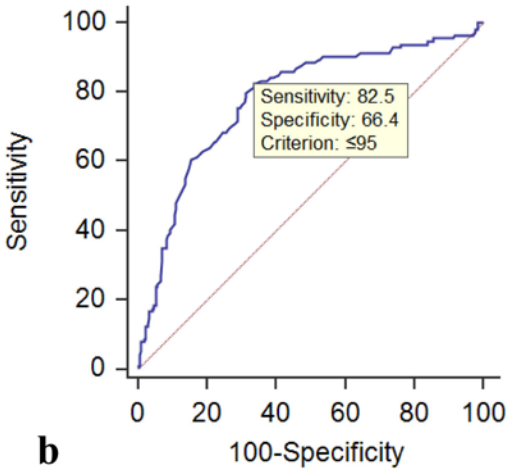
Previous studies stressed the cut-off value of HU for screening osteoporosis with a significant correlation between HU using lumbar CT and BMD by DEXA [8, 14, 22, 24]. In the current study, we hypothesized that HU compared with QCT values would yield a more accurate cut-off value for diagnosing osteoporosis. Additionally, we compared the cut-off values of HU comparing the spine and femur DEXA.

In the present study, we analyzed the HU value comparing with QCT after dividing the subjects into two groups, osteoporosis and non-osteoporosis. Our results for measurement of the HU value were reliable, with excellent inter-observer reliability of 0.961(p=0.000). The optimal cut-off value of HU was 146 compared to the QCT values for diagnosing osteoporosis. The cut-off value of HU comparing spine and femur DEXA indicate 95 and 86, respectively. The sensitivity and specificity were highest in QCT with 94.3% sensitivity and 87.5% specificity. The cut-off value of HU decreases in the order of QCT, spine DEXA, and femur DEXA for screening osteoporosis. Therefore, the most sensitive results can be obtained when compared with spine QCT. Furthermore, the cut-off value of this study was higher than that reported in previous studies. The results stress that the cut-off values of HU in the previous reports comparing DEXA may be incorrect. It is possible that overestimated DEXA results were used in previous studies. The optimal cut-off value of this study represents that the HU values comparing with QCT are more sensitive for screening osteoporosis than CT than the results comparing with DEXA.

Our study has some limitations. First, the HU value comparing with QCT is not perfect tool for diagnosing osteoporosis and this comparison is a surrogate measurement. Second, HU measurement is not possible in the following situations: fracture, spondylitis and instrumented level. Third, the results of this study did not provide evidence that the method can be applied to the cervical and thoracic spine. Finally, our study did not distinguish osteoporosis, osteopenia and normal group because of small sample size. We analyzed the results in two groups including osteoporosis and non-osteoporosis. Therefore, this study does not provide the optimal cut-off value to diagnose osteopenia.

In conclusion, HU obtained from lumbar CT showed a significant correlation with BMD based on QCT and DEXA scan. Significant correlation was found between HU measurement and QCT value. HU value threshold of 146 on lumbar CT was the most sensitive (94.3%) and specific (87.5%) single measurement for assessment of osteoporo-





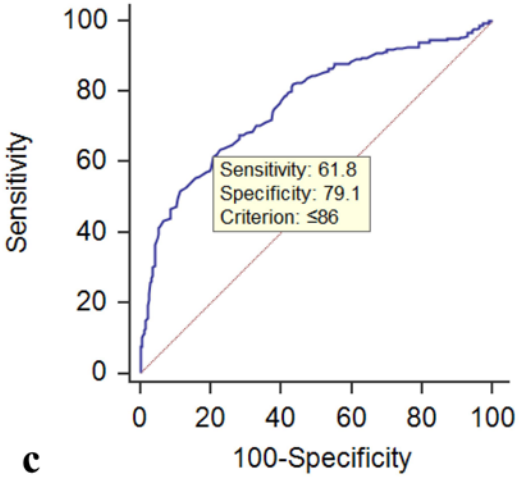


Figure 3: ROC curve for predicting osteoporosis based on HU measurement compared with QCT and DEXA scans.

(a) Spine QCT, (b) Spine DEXA, (c) Femur DEXA

sis. We suggest that the HU measurement might be useful for predicting osteoporosis before spine fusion surgery with reduced radiation hazard.

Conflict of interest statement: Authors state no conflict of interest

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