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Correlation Between Hounsfield Units Measured by Diagnostic Noncontrast Enhanced CT in Lumbar Spine and Femoral Neck With Bone Mineral Density Measured by Dual-Energy X-Ray Absorptiometry

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Background: Computed tomography (CT) is widely available and measurement of Hounsfield unit (HU) is easy and reproducible. Can this measurement predict osteoporosis?

Objective: To evaluate correlation between HU of the lumbar spine and femoral neck and bone mineral density T-score (BMD T-score), and to assess the cutoff HU values at the lumbar spine and femoral neck to predict osteoporosis.

Methods: This retrospective study reviewed 237 patients who underwent both dual-energy x-ray absorptiometry (DXA) and CT within an interval of 1 year from January 2014 to August 2022. HU at the L1-L4 lumbar spine and femoral neck, as well as BMD T-score for the same regions were determined. Correlation of BMD T-score and HU was evaluated using Pearson correlation. Receiver operating characteristic (ROC) curves were generated to determine the cutoff HU values for predicting osteoporosis and its sensitivity, specificity, positive, and negative predictive values.

Results: Among 205 patients included, 64 (31.2%) had osteoporosis. At the lumbar spine, the average HU was moderately correlated with the BMD T-score ($r = 0.639$; 95% CI, 0.550 - 0.714), whereas at the femoral neck, the average HU had a good correlation with BMD T-score ($r = 0.756$; 95% CI, 0.691 - 0.809). Cutoff values for predicting osteoporosis were 155 HU at the lumbar spine and 130 HU at the femoral neck.

Conclusions: HU and BMD T-score were more strongly correlated at the femoral neck than at the lumbar spine. A cutoff HU value of 130 at the femoral neck was used for predicting osteoporosis in Thai people.

Keywords: DXA, Bone density, CT scan, Osteoporosis

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Introduction

Approximately one-third of elderly women and one-fifth of elderly men worldwide will have experienced osteoporotic fractures.[1] Osteoporosis, which is characterized by low bone mass, causes fragility of the bone that can lead to fractures or nonunion of the bone after surgery. According to the Thai Osteoporosis Foundation (TOPF) and the American Association of Clinical Endocrinology (AACE) guidelines, osteoporosis is diagnosed based on the presence of fragility fractures in the lumbar spine or hip or bone mineral density T-score (BMD T-score) of -2.5 or less at these skeletal sites determined using dual-energy x-ray absorptiometry (DXA) in the absence of a fracture.[2] Although DXA has been considered the gold standard for diagnosis of osteoporosis, with a greater radiation safety (0.009 - 0.027 mSv) than does computed tomography (CT) (0.06 - 2.5 mSv),[3] its availability is much more limited than that of CT in many hospitals. When patients undergo CT for the nonosteoporotic reasons, such as abdominal pain or suspected renal calculi, the additional Hounsfield unit (HU) measurements at the lumbar spine and femoral neck may help identify individuals at high risk for fragility fractures.

In previous studies, the correlation between HU and BMD measurements at the lumbar spine and their cutoff values for discriminating between osteoporosis and nonosteoporosis conditions have varied depending on the ethnicity and age group.[4-10] Moreover, these studies showed that the correlations between HU and BMD measurements in this skeletal site were not strong.[4-10] Although the region of interest (ROI) for HU measurements is located on the trabecular bone structure, ROI for BMD measurement include both trabecular and cortical bones. This difference in technique may promote notable discordance in results between HU and BMD values. Previous study reported a very strong correlation between HU and quantitative computed tomography (QCT) in the lumbar spine (L1-L3).[9] However, QCT is not as widely used as DXA given its high cost and radiation exposure. Hence, the HU of the femoral neck has the potential to be a more accurate approach to predicting individuals at high risk for osteoporosis.

This study aimed to investigate the correlation between HU measured with CT and BMD T-score measured using DXA at the femoral neck and lumbar spine, and also assessed the cutoff HU at lumbar spine and femoral neck to predict osteoporosis.

Methods

Participants

This retrospective diagnostic study reviewed 237 patients. Inclusion criteria were menopause females or males aged 50 years and older who underwent both central DXA and CT at Burapha University Hospital within a 12-month interval from January 2014 to August 2022. A 1-year interval between CT and DXA given that changes in the T-score take a long time were observed. Park et al[11] revealed that the change from severe osteopenia to osteoporosis took around 1.5 years, with the change from healthy or mild osteopenia to osteoporosis needing much more time. Previous study used an interval of up to 2 years.[4] Notably, 32 patients were excluded due to spinal fixation (n = 11), hip replacement (n = 1), incomplete CT imaging (n = 6), multilevel of compression fractures (n = 5), and severe spine degeneration (n = 9). Sample size calculation was conducted according to previous study, which subsequently showed that at least 201 subjects were required in this study.[12] CT images and BMD of all participants from the picture archiving and communication system (Infinitt PACS, Seoul, South Korea) were collected and then measured the HU of the spine.

Ethics

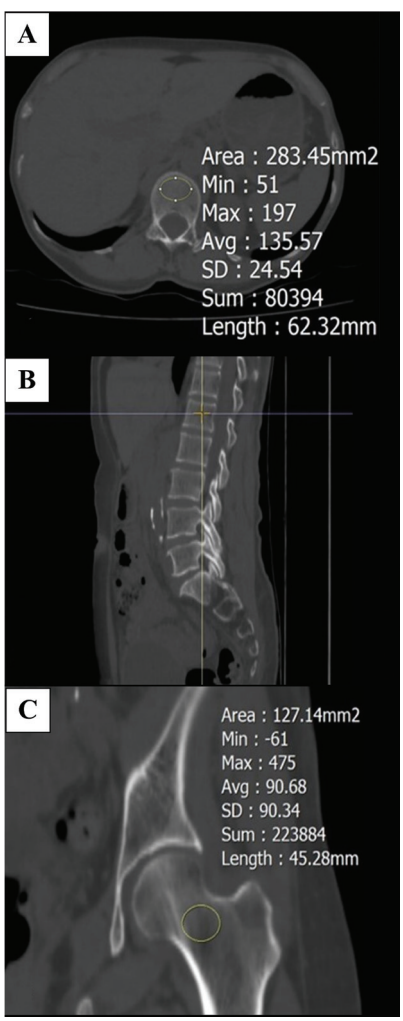
This study was approved by the Institutional Review Board of Burapha University. The number of approval decision was IRB1 090/2565 on October 5, 2022.

Imaging Protocol

HU of the femoral neck and lumbar spine (L1-L4) vertebrae were obtained from noncontrast whole abdominal CT, CT colonoscopy, and CT of the urinary tract. HU of the lumbar spine was measured using the simple ROI

technique, as described by Pickhardt et al[6] (Figure 1A and 1B). Previous study showed good correlation between angled and non-angled measurements.[11] HU of the femoral neck was measured in the coronal view (Figure 1C). ROIs were placed as large as possible at each level of lumbar spine and femoral neck without acquisition of cortex and basivertebral vein. All CT imaging were performed on a 64-slice multidetector CT (MDCT) scanner (Toshiba Aquilian, Otawara, Japan) with axial, coronal, and sagittal reconstruction.

Figure 1. HU Measurement Using Simple ROI Technique



Abbreviations: HU, Hounsfield unit; ROI, region of interest.
A, B, The ROI was placed at the L1 level in the axial view compared to sagittal view.
C, ROI was placed at the femoral neck in the coronal view.

BMD and BMD T-score at the femoral neck and lumbar spine were obtained using a DXA scanner (GE Lunar Prodigy Bone Densitometer, Wisconsin, US). Osteoporosis was diagnosed based on TOPF and AACE guidelines.

In the absence of fragility fractures, osteoporosis was defined based on a lumbar spine or hip T-score of -2.5 or below.[2] Osteopenia was defined based on a T-score between -1.0 and -2.4. In this study, osteoporosis was diagnosed according to the AACE guideline and World Health Organization (WHO) classification, in which the lowest T-score of either the lumbar spine or hip should be -2.5 or below.

Statistical Analysis

Categorical data were presented as frequency and percentage, whereas continuous data were presented as mean and standard deviation (SD). Pearson correlation (r) was used to determine the correlation between HU and BMD T-score. The cutoff HU by comparing the ROC and area under the curve (AUC) between the nonosteoporosis and osteoporosis group were determined. Youden index was calculated. Youden index is commonly used for measurement of diagnostic effectiveness which is a function of sensitivity and specificity. Moreover, the accuracy of the identified cutoff in terms of sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were also determined. The threshold for statistical significance was set at $P < .05$.

Results

The characteristics of patients included in this study were summarized. Notably, a total of 205 patients had a mean (SD) age of 67.2 (9.5) years, most of whom were female (87.3%). The prevalence of osteoporosis was 31.2% (Table 1).

HU showed stronger correlation with BMD T-score at the femoral neck (r = 0.756; 95% Confidence interval [CI], 0.691 - 0.809) than at the lumbar spine (r = 0.639; 95% CI, 0.550 - 0.714) (Figure 2).

The optimal cutoff value for discriminating between individual with an osteoporosis and nonosteoporosis at the lumbar spine was equal or less than 117 HU, and a Youden index of 0.61 (Table 2), with an AUC of 0.876 (95% CI, 0.829 - 0.923) (Figure 3), sensitivity of 85.9% (95% CI, 75.0% - 93.4%), and specificity of 75.2% (95% CI, 67.2% - 82.1%).

The optimal cutoff value for HU at the femoral neck was equal or less than 80, and a Youden index of 0.51, with an AUC of 0.828 (95% CI, 0.768 - 0.888) (Figure 3), sensitivity of 79.7% (95% CI, 67.8% - 88.7%), and specificity of 70.9% (95% CI, 62.7% - 78.3%). At 100% sensitivity, the cutoff values at the lumbar spine and femoral neck were 155 and 130 HU, respectively.

Table 1. Clinical Data of Patients

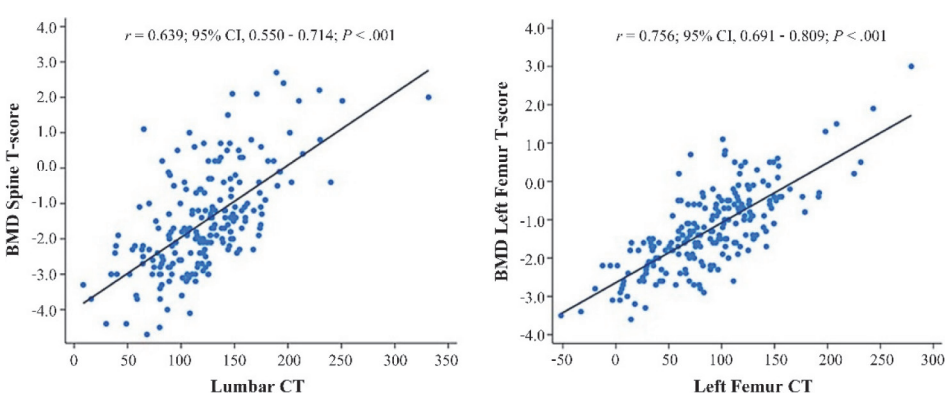
Characteristic	No. (%)		
	Total (N = 205)	Osteoporosis (n = 64)	Nonosteoporosis (n = 141)
Gender			
Male	26 (12.7)	4 (6.3)	22 (15.6)
Female	179 (87.3)	60 (93.7)	119 (84.4)
Age, y			
< 60	43 (21.0)	9 (14.1)	34 (24.1)
60 - 69	89 (43.4)	23 (35.9)	66 (46.8)
70 - 79	49 (23.9)	19 (29.7)	30 (21.3)
≥ 80	24 (11.7)	13 (20.3)	11 (7.8)

Table 2. Diagnostic Performances for the Prediction of Osteoporosis

Test	Cutoff	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Lumbar CT	≤ 117*	85.9 (75 - 93.4)	75.2 (67.2 - 82.1)	61.1 (50.3 - 71.2)	92.2 (85.7 - 96.4)
	≤ 155	100.0 (94.4 - 100.0)	26.2 (19.2 - 34.3)	38.1 (30.7 - 45.9)	100.0 (90.5 - 100.0)
Left femur CT	≤ 80*	79.7 (67.8 - 88.7)	70.9 (62.7 - 78.3)	55.4 (44.7 - 65.8)	88.5 (81.1 - 93.7)
	≤ 130	100.0 (94.4 – 100.0)	23.4 (16.7 - 31.3)	37.2 (30.0 - 44.9)	100.0 (89.4 - 100.0)

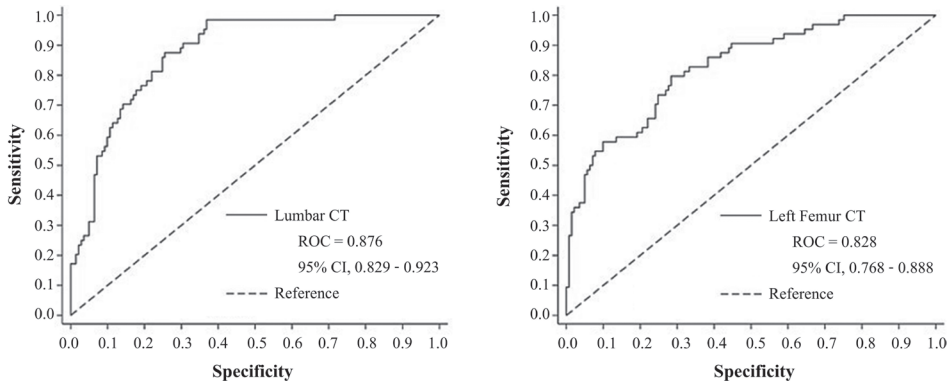
Abbreviations: CI, confidence interval; CT, computed tomography; NPV, negative predictive value; PPV, positive predictive value.
* The best threshold value was determined using Youden index (Youden index = Sensitivity + Specificity -1).

Figure 2. Scatter Plot Correlation Between HU and BMD T-Score at the Lumbar Spine and Femur



Abbreviations: BMD, bone mineral density; CI, confidence interval; CT, computed tomography; HU, Hounsfield unit.

Figure 3. ROC Curves for the Detection of Osteoporosis Based on Hounsfield Units at the Lumbar Spine and Femur



Abbreviations: ROC, receiver operating characteristic; CI, confidence interval; CT, computed tomography; HU, Hounsfield unit.

Discussion

CT is more widely available than is DXA, with noncontrast CT being able to measure HU easily and reproducibly without the need for extra radiation exposure. Prior studies have shown a positive correlation between HU and DXA at the lumbar spine (r range = 0.489 - 0.774).[4-10] The present study confirms a moderate correlation between the average HU and DXA at the L1–L4 lumbar spine (r = 0.639). This moderate correlation is probably due to differences in techniques between DXA and CT. DXA is a 2-dimensional imaging technique that is obtained in anteroposterior fashion and includes the cortical bone, facet joints, osteophytes, and sometimes aortic calcification, which trends to increase the BMD value. In contrast, CT is a 3-dimensional imaging technique that can measure the HU of the trabecular bone.

The current study found that the HU had a stronger correlation with the DXA T-score at the femoral neck (r = 0.756), which could be attributed to the low influence of degenerative changes on HU of the femoral neck. However, the femoral neck is a smaller area, which may lead to measurement variations. In this study, HU was measured in the coronal view, which is slightly different from the oblique coronal view used for DXA. However, measurements in the coronal view were much easier and faster with CT, making it more practical in real life.

Islamian et al[5] reported a correlation coefficient of 0.766 (P < .001) between HU from CT and DXA in osteoporotic Egyptian patients and suggested a threshold of 155 HU at L1, which had 100% sensitivity in the diagnosis of osteoporosis. Pickhardt et al[6] found that HU value of 160 at the L1 level showed 100% sensitivity for osteoporosis and that an average HU value of 145 at T12-L5 had 100% sensitivity for the condition. A study in South Korea by Kim et al[8] suggested an optimal cutoff value of 146 HU at the lumbar spine with QCT, showing 94.3% sensitivity and 87.5% specificity. Using Youden index, the cutoff value for HU on lumbar spine CT in this study was determined to be 117 HU with 85.9% sensitivity, whereas the cutoff for HU on left femur CT was 80 HU with 79.7% sensitivity. For 100% sensitivity, the cutoff values were 155 and 130 HU at the lumbar spine and left femur, respectively. Cutoff values for each study slightly differ possibly due to differences in the ethnicity of participants. This study aimed to use HU as an opportunistic screening tool for osteoporosis in at risk Thai patients who underwent abdominal CT scan for other reasons. Additional HU measurements at the lumbar spine and femoral neck to screen for osteoporosis carries no addition cost or radiation exposure with minimal time needed. If CT show positive findings, further DXA should be performed for the confirmation of diagnosis and follow-up after treatment. This study suggested using an optimal cutoff value with 100% sensitivity.

This study has some limitations. First, we did not evaluate the effects of contrast material administration on the HU of the trabecular bone, suggesting that our findings do not apply to contrast-enhanced CT. Second, this study was conducted at a single institution.

Conclusions

CT has moderate correlation with DXA and can be used as an opportunistic screening test. Patients with a left femoral density less than 130 HU and lumbar density less than 155 HU undergo DXA for diagnostic confirmation of osteoporosis.

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ความสัมพันธ์ระหว่างการวัดค่าเฮานส์ฟิลด์ยูนิตด้วยเครื่องเอ็กซเรย์คอมพิวเตอร์ในตำแหน่งของคอกระดูกต้นขาและกระดูกสันหลังส่วนล่างกับการวัดค่าความหนาแน่นมวลกระดูกด้วยเครื่องตรวจความหนาแน่นของกระดูกสองพลังงาน

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บทนำ: เอ็กซเรย์คอมพิวเตอร์มีใช้อย่างแพร่หลายและการวัดค่าเฮานส์ฟิลด์ยูนิต (Hounsfield unit, HU) สามารถทำได้ง่าย การวัดนี้อาจจะสามารถใช้ในการทำนายโรคกระดูกพรุน

วัตถุประสงค์: เพื่อหาความสัมพันธ์ของค่าเฮานส์ฟิลด์ยูนิตที่ได้จากการวัดกระดูกต้นขาและกระดูกสันหลังส่วนล่าง และความหนาแน่นของกระดูกที่ได้จากการวัดด้วยเครื่องตรวจความหนาแน่นของกระดูกสองพลังงาน และหาจุดตัดของค่าเฮานส์ฟิลด์ยูนิตที่สามารถทำนายภาวะกระดูกพรุน

วิธีการศึกษา: การศึกษาย้อนหลังในกลุ่มตัวอย่างผู้ป่วย จำนวน 237 คน ที่เข้ารับการตรวจด้วยเครื่องตรวจความหนาแน่นของกระดูกสองพลังงานและเครื่องเอ็กซเรย์คอมพิวเตอร์ตั้งแต่เดือนมกราคม พ.ศ. 2557 ถึงเดือนสิงหาคม พ.ศ. 2565 เก็บข้อมูลค่าเฮานส์ฟิลด์ยูนิตและค่า T-score จากกระดูกสันหลัง (L1-L4) และกระดูกต้นขา ประเมินความสัมพันธ์ระหว่างค่า T-score และค่าเฮานส์ฟิลด์ยูนิตโดยใช้สถิติ Pearson correlation และประเมินจุดตัดของค่าเฮานส์ฟิลด์ยูนิตเพื่อใช้ทำนายโรคกระดูกพรุน

ผลการศึกษา: ผู้ป่วยที่เข้าร่วมในการศึกษานี้ จำนวน 205 คน พบว่า ผู้ป่วย 64 คน (ร้อยละ 31.2) เป็นโรคกระดูกพรุน ค่าเฮานส์ฟิลด์ยูนิตจากกระดูกหลังสันหลัง (L1-L4) มีความสัมพันธ์ปานกลางกับค่า T-score (r = 0.639; 95% CI, 0.550 - 0.714) และค่าเฮานส์ฟิลด์ยูนิตจากกระดูกต้นขามีความสัมพันธ์ในระดับสูงกับค่า T-score (r = 0.756; 95% CI, 0.691 - 0.809) ค่าเฮานส์ฟิลด์ยูนิตจากกระดูกสันหลังส่วนล่างเท่ากับ 155 และจากกระดูกต้นขาเท่ากับ 130 มีความไวต่อการตรวจหาโรคกระดูกพรุนร้อยละ 100

สรุป: การวัดค่าเฮานส์ฟิลด์ยูนิตจากกระดูกต้นขามีความสัมพันธ์กับการวัดค่าความหนาแน่นมวลกระดูกมากกว่าจากกระดูกสันหลัง จุดตัดค่าเฮานส์ฟิลด์ยูนิตเท่ากับ 130 สามารถใช้คัดกรองโรคกระดูกพรุนในผู้ป่วยคนไทย

คำสำคัญ: เครื่องตรวจความหนาแน่นของกระดูกสองพลังงาน มวลกระดูก เอ็กซเรย์คอมพิวเตอร์ กระดูกพรุน

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