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Hounsfield unit for the diagnosis of bone mineral density disease: A proof of concept study

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ABSTRACT

Objectives: Our aim is to correlate Hounsfield units (HU) from lumbar Computed Tomography scans (CT) with Bone Mineral Density (BMD) values from Dual-energy X-ray Absorptiometry scans (DXA) for the diagnosis of bone mineral density disease.
Methods: We enrolled 114 women, conducted both CT and DXA scans on them to assess the correlations between the mean lowest HU at lumbar vertebrae and the BMD values from DXA scan. Statistical analysis was used to assess the correlations between HU and the patients' BMD and age.
Results: We noted moderate correlations between the lowest HU at L1–L4 and the BMD from DXA scan which is significant (correlation coefficient, 0.563). DXA scans showed a normal BMD in 33.3% of patients, osteopenia in 43.9%, and osteoporosis in 22.8% respectively. We also determined that a HU of 203 would exclude osteoporosis (90% sensitivity for normal BMD) and a threshold of <91 would exclude normal bone mineral density (86% sensitivity for osteopenia, 60% sensitivity for osteoporosis). Mean HU values consistently decreased with increasing decade of life, from 182.8 ± 42 in the fourth decade to 82.13 ± 32 in the eighth (correlation coefficient, 0.527).
Conclusions: HU values are moderately correlated with the patients' age and BMD values from DXA scan, with 203, safely excluding osteoporosis and <91 excluding normal BMD. Prospective studies with a larger number of patients are needed, where multiple thresholds could be applied and more distinguished values for normal bone density, osteopenia, and osteoporosis can be obtained.

Introduction

The gold standard technique for measurement of Bone Mineral Density (BMD) is the Dual-energy X-ray Absorptiometry (DXA). Dual-energy X-ray Absorptiometry is a noninvasive and X-ray based absorptiometry, with high precision (<1%) in normal weight population. It is widely available and has replaced all older BMD measurement techniques.

In the year 1970, a test for BMD using quantitative computed tomography (CT) scans was introduced.[1] This technique uses standardized software and phantom calibration, with results expressed in terms of milligram per cubic centimeter of the trabecular bone at the center of the vertebral body.[2,3] However, with the introduction of DXA, because of the long scanning period with quantitative CT and the relatively high radiation dose, use of quantitative CT has been limited in clinical practice and has been confined to musculoskeletal research fields.[4]

Approximately 6280 million CT scans are performed annually in the United States alone.[5,6] Bone mineral density data and their attenuation coefficients (Hounsfield units [HU]), which are obtained from diagnostic CT examinations performed for any clinical condition, are available to researchers for osteoporosis screening at no additional cost, patient time, equipment or radiation exposure.[7]

The World Health Organization's criteria for diagnoses of osteoporosis and osteopenia from DXA scan are not directly transferrable to quantitative CT data, because quantitative CT data are based on trabecular bone, and exclude the cortical bone.[8] In order to make use of the HU value available from diagnostic CT scans for BMD assessment, researchers use phantomless or external reference phantom to convert HU values to quantitative CT (milligrams per cubic centimeter).[9,10] In addition, high correlations between quantitative CT and spiral CT, HU values have been found,[4] along with good correlations between HU values from CT scans and T scores from DXA scans for diagnosis of BMD diseases.[7]

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In this study, we retrospectively collected data from 114 patients to evaluate the correlation between HU values at lumbar spine, from abdominal CT examinations obtained for various medical indications and BMD values, T Score from DXA scans to diagnose BMD disease. In particular, we examined the sensitivity of HU values for the diagnosis of osteoporosis. Correlations between HU values and patients' age were also assessed.

Methods

Patient cohorts

This work received approval from the ethics committee at King Abdulaziz University Hospital. We retrospectively reviewed consecutive female patients, aged 40 years and older who were referred for DXA scan, for screening or for follow-up of BMD disease, and who had lumbar CT scan done within a 1 year interval. Computed tomography scans of the abdomen, pelvis, lower limb angiogram, lumbar and thoracolumbar areas were included. Patients who had previous spine surgeries with spinal instrumentation, implantation, or vertebroplasty were excluded from the study. Patients with lumber deformity, lumber fracture, or a significant degenerative disease at the lumber spine were also excluded, as the BMD would be overestimated by the DXA scan. 18 patients (15%), having mild degenerative disease were included in the study. Our review included approximately 2000 patients, with 114 patients meeting the inclusion criteria.

Dual-energy X-ray absorptiometry

Dual-energy X-ray Absorptiometry scans of the lumbar spine from the first through to the fourth lumbar vertebrae (L1–L4), and proximal femora were performed using standard techniques (GE Healthcare LUNAR Prodigy densitometer). The WHO's classification of BMD was used. With the use of the lowest reported T score in the lumber spine or proximal femora, the following T scores were used to determine patients' diagnoses: ≤ -2.5, osteoporosis; between -1.0 and -2.5, osteopenia; and ≥ -1.0, normal BMD.[11]

Computed tomography

Computed tomography was conducted using multidetector CT scanners. We retrospectively accessed the CT images and evaluated the vertebral BMD on a standard radiology picture, archiving and communication system work station. Bone windows had the following levels: window width = 3000 and window level = 700. In the 49 CT scans, 42.9% were performed after the oral and intravenous contrast agent administration, with 57.1% having no contrast agent (Somatom, Siemens, 64 slices, and Definition AS, Siemens, 128 slices). Images were acquired with multislice technique and reconstruction protocol (slice thickness of 5 mm for abdomen and 2 mm for pelvis). The HU measurement for each vertebra was obtained using previously described protocols from Lee and associates[12] and from Schreiber and associates.[13] The largest possible round region of interest was drawn, excluding the cortical margins, to prevent volume averaging on the axial images at lumbar L1 through L4. Hounsfield unit values from 3 separate locations were measured: immediately inferior to the superior endplate, in the middle of the vertebral body, and superior to the inferior endplate (Fig. 1). For each lumbar vertebra, the lowest HU value among the 3 was used, giving the mean HU value of L1 through L4.

Statistical analyses

Differences in HU values between age groups were evaluated with the use of a 1-way Analysis of Variance (ANOVA). Correlations between HU values and age group and between HU values and BMD values from DXA, were determined. Correlations between BMD values from DXA scan and the lowest HU value at each lumber vertebra were measured using the Pearson correlation.

We calculated the sensitivity and specificity for CT imaging and compared it with DXA imaging across a range of observed lowest CT attenuation values (HU) to establish the thresholds that would yield 95% sensitivity and 95% specificity for distinguishing between osteoporosis and non-osteoporosis (osteopenia and normal BMD), and between normal BMD and low BMD (osteoporosis and osteopenia). In addition, we assessed areas under the Receiver Operating Characteristic curves, ROC (areas under the curves AUC) and the corresponding 95% confidence limits for L1–L4 vertebrae.

Results

Among the 114 women who fit into the inclusion criteria, their mean age was 58 ± 10 years (range, 40–87 y). The mean average time between the CT scan and the DXA scan was 68 ± 2 days. Most of the CT scans were performed for metastatic work up (70%), with 20% for renal and other causes and 10% for investigation of abdominal pain (Table 1). The mean HU value across L1 to L4 was 157 ± 57 (range, 14–578). Mean BMD value as measured by DXA scan was 0.885 ± 0.15 g/cm^2, mean DXA score was −1.91 ± 1.26, with T scores ranging from −5.4 to −1.1. Twenty-six patients (22.8%) had T scores of less than 1 (indicating normal BMD), 50 patients (43.9%) had T scores of more than 1 (indicating osteopenia), and 38 patients (22.8%) had T scores of more than −2.5 (indicating osteoporosis) respectively (Table 1). The diagnosis of BMD in 45 patients (39.5%) was based on the femoral T score, as it showed the lowest BMD values versus that shown with lumber spine, with the diagnosis of osteoporosis in 14 patients (31%) based on femoral T score. Mean height, weight and body mass index for all patients are shown in Table 1.

The correlation between the lowest HU values obtained at each lumber vertebra at L1–L4 on CT scan, and the absolute BMD value for DXA scan is shown in Table 2. Moderate correlations were noted throughout all the lumber vertebrae, which are statistically significant ($p < 0.001$), and the correlation coefficient (r) at L1 is 0.509, L2 of 0.473, L3 of 0.492, and L4 of 0.525 and (r) at L1–L4 is 0.563.

The mean HU values were stratified into the 3 groups of T scores (normal, osteopenia, and osteoporosis), in which the mean HU value for normal T score was 184.6 ± 47 (95% confidence interval [CI] 165.6–203), HU value for osteopenia T score was 145.3 ± 43.6 (95% CI, 132.9–157.7), and HU value for osteoporosis T score was 107.8 ± 51.1 (95% CI, 91.02–124.6) (Table 3). As shown in Table 3, HU values at 91 can safely exclude normal BMD, and HU values at 203 can safely exclude osteoporosis. Further analysis of the cutoff points according to the ROC (Fig. 2) showed an HU value of 91 as the cutoff point associated with patients who were at high risk of BMD disease (86% sensitivity for high-risk osteopenia and 60% sensitivity for osteoporosis) and HU value of 203 as the cutoff point for patients at low risk of having BMD disease (normal and near normal BMD, with 90% sensitivity for normal and 73% sensitivity for mild osteopenia).

For all patients, the HU values consistently decreased with increasing decade of life throughout all measured lumbar vertebra bodies, demonstrating a moderate correlation (correlation coefficient, 0.527; Fig. 3). HU values and absolute BMD values in DXA scan demonstrated a similar pattern of continuous decrease across increasing age groups (Fig. 4). Differences in mean HU values and absolute BMD values were significant among different age group