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Original Article

Inverse Correlation at the Hip Between Areal Bone Mineral Density Measured by Dual-Energy X-ray Absorptiometry and Cortical Volumetric Bone Mineral Density Measured by Quantitative Computed Tomography

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Abstract

Quantitative computed tomography (QCT) is considered to measure true volumetric bone mineral density (vBMD; mg/cm^3) and enables differentiation between cortical and trabecular bone. We aimed to determine the value of QCT by correlating areal BMD (aBMD) by dual-energy X-ray absorptiometry (DXA) with vBMD when using a fixed threshold to delineate cortical from trabecular bone. In a cross-sectional study, 98 postmenopausal women had their hip scanned by DXA and by QCT. At the total hip and the trabecular bone compartment, aBMD correlated significantly with vBMD ($r = 0.74$ and $r = 0.63$; $p < 0.01$, respectively). A significant inverse correlation was found between aBMD and cortical vBMD ($r = -0.57$; $p < 0.01$). Total hip volume by QCT did not change with aBMD. However, increased aBMD was associated with a decreased trabecular bone volume ($r = -0.36$; $p < 0.01$) and an increased cortical volume ($r = 0.69$; $p < 0.01$). Changing the threshold used to delineate cortical from trabecular bone from default 350 mg/cm^3 to either 300 or 400 mg/cm^3 did not affect integral vBMD ($p = 89$) but had marked effects on estimated vBMD at the cortical ($p < 0.001$) and trabecular compartments ($p < 0.001$). Furthermore, increasing the threshold decreased cortical thickness ($p < 0.001$), whereas the strength parameter in terms of buckling ratio increased ($p < 0.001$). Our results show good agreement between aBMD and integral vBMD. However, using a fixed threshold to differentiate cortical from trabecular bone causes an apparent increase in cortical volume with a decrease in cortical density as aBMD increases. This may be caused by the classification of a larger part of the transition zone as cortical bone with increased aBMD.

Key Words: QCT; DXA; vBMD; aBMD.

Introduction

Osteoporosis is a disease resulting from a reduced bone mass with altered bone geometry and microstructure leading to an increased risk of fractures. Since 1994, the World Health Organization's definition of osteoporosis based on T-scores, assessed by dual-energy X-ray absorptiometry (DXA) scans, has been the gold standard in diagnosing osteoporosis *(1)*. However, the DXA techniques have limitations as they may overestimate bone mineral density (BMD) in overweight people *(2)*, patients with osteoarthritis *(3)*, scoliosis, aortic calcification, and vertebral fractures *(4)* and underestimate BMD in individuals with relatively small bones *(5)*. Furthermore, DXA images are 2-dimensional (2D) assessments of the areal BMD (aBMD; g/cm^2), which do not account for alterations in microstructure and geometry or the relative distribution of

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cortical and trabecular bone. For this matter, 3-dimensional (3D) imaging by quantitative computed tomography (QCT) may serve as a better alternative as QCT scans are considered to provide a measure of true volumetric BMD (vBMD; mg/cm^3) including the ability to distinguish between cortical and trabecular bone(6,7).

Today, there is an increasing interest in the use of 3D CT-based techniques in relation to osteoporosis (8,9). Whether 3D measuring techniques can improve fracture prediction compared with DXA has not been fully evaluated, and the replacement of DXA scan with QCT in diagnosing osteoporosis in daily practice is still challenging as the amount of radiation by QCT far exceeds that of the DXA scan (10). The advantages, however, of a more differentiated measurement outcome provided by QCT scans may give us more information on indices of importance to fracture risk. Furthermore, it may supply more detailed information on effects of diseases or treatments on changes in bone mineral distribution.

Despite the fact that clinical studies more frequently use images from both DXA and QCT in their evaluation of bone and bone changes, little information exists regarding the correlation between these 2 techniques. If QCT images shall serve as a true supplement, or even a replacement, to DXA, it is of interest to examine the association between the mentioned indices. Therefore, in the present study, we aimed to investigate the extent to which aBMD at the hip, as assessed by 2-dimensional DXA scans, correlates with total, trabecular, and cortical vBMD as assessed by 3D QCT scanning technique and whether the indices are affected by the cortical threshold used to separate cortical and trabecular bone.

Methods

Study Population

We studied 98 postmenopausal women aged 63 years (range: 56−76 years) who had been recruited from the general background population. Eighty-one healthy women were diagnosed with osteopenia as they had been screened by DXA and included in an ongoing randomized trial (NCT01690000). Data on the women derive from baseline before any study-related action was taken. Seventeen of the included women had been recruited as healthy controls in another study and did not have DXA scans performed before their inclusion, that is, they were not selected or included because of a known low bone mass (11,12).

Exclusion criteria for all participants were impaired renal function (plasma creatinine >120 μmol/L), hypercalcemia (plasma ion >1.32 mmol/L), intestinal malabsorption, impaired liver function, medical conditions known to affect bone, including the use of drugs with effects on calcium homeostasis and bone metabolism such as antiresorptives, and bone anabolic agents as well as diuretics and lithium. None of our participants were on treatment with experimental drugs at the time of investigations.

All patients had provided an informed consent before conducting the studies. Both studies are approved by the regional ethic committee of Denmark (#M-2010-0296; M#2012-252-12).

Osteodensitometry by DXA

We measured aBMD (g/cm^2) on the left hip region using Hologic Discovery scanners (Hologic, Inc., Waltham, MA). All scanners were daily crosscalibrated with a reference phantom to read BMD.

Osteodensitometry by QCT

We measured vBMD (mg/cm^3) at the left hip by QCT using a Philips Brilliance 40 slices multidetector helical CT scanner (Phillips, Eindhoven, the Netherlands). We scanned with a dose modulation tool (Z-DOM; Phillips) at a voltage of 120 kV. Slice thickness and slice spacing was 3 mm. Field of view was 400 mm and collimation was 40×0.625 mm at the hip. The vBMD was determined using CTXA Hip Exam Analysis protocol, QCTPro (version 4.2.3; Mindways Software, Inc., Austin, TX) in conjunction with a solid-state CT calibration phantom (Model 3; Mindways Software), which was scanned simultaneously with the patients. We performed analysis of the left proximal femur by automatic bone segmentation including the total hip and femoral neck (13). In addition to densitometric measures, we also used the Mindways software to estimate cortical thickness and bone strength as assessed by buckling ratio (BR) at the femoral neck. For initial analyses, the separation algorithm for cortical bone was set at default 350 mg/cm^3. In addition, in a subgroup of 50 randomly selected study patients, we studied the correlations between aBMD and vBMD by changing the threshold, delineating cortical from trabecular bone, to 300 and 400 mg/cm^3.

The reproducibility (coefficient of variation [%]) of the analyses by QCTPro was calculated by repeating evaluation analyses of 10 patients' data showing a total hip vBMD coefficient of variation of 0.8%.

Statistical Analysis

We report results as mean ± standard deviation or median with interquartile range (IQR: 25%−75%) unless otherwise stated. Groups were compared using a 2-sample t test or 1-way analyses of variance. Associations between variables were assessed by bivariate correlations calculating Pearson's correlation coefficient (r). Furthermore, we studied associations by using linear regression analysis adjusting for body mass index (BMI) and age. Results from these analyses are reported as unstandardized regression coefficient B (β) with 95% confidence interval (CI). $p < 0.05$ Was considered statistically significant. We used IBM SPSS Statistics, version 21 (IBM, New York) for the statistical analyses.

Results

Descriptive data are listed in Table 1. Mean age of the 98 participants was 63 years (range: 56−76 years). Associations between studied indices at the total hip are shown in Fig. 1.