Trabecular Bone Mineral Density Measurement Using Thoracic and Lumbar Quantitative Computed Tomography

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Purpose: To evaluate the agreement of bone mineral density (BMD) between lumbar (L) and individual thoracic (T) vertebrae and identify a standard thoracic spine level for BMD assessment in cardiac computed tomography (CT) images.

Materials and Methods: Three hundred subjects who underwent simultaneous chest and abdomen CT scans for clinical indications were included. A calibration phantom that extended from the first thoracic spine (T_1) to the fifth lumbar (L_5) was employed. Vertebral BMD were measured by QCT 5000 and NVivo systems. The association between three consecutive lumbar (L1–L3) and thoracic BMD (3T, initiation site equivalent to left main coronary caudally) was evaluated.

Results: There was a gradual decrease in BMD values from T_1 to L_3, subsequently increasing in L_4 and L_5 in both genders. When stratified by gender, 3T BMD was significantly higher versus L_{1-3} BMD (156.9 versus 141.9vmg/cm^3, $P < .001$) for women as well as for men (164.8 versus 151.0 mg/cm^3, $P < .001$). There is good correlation between 3T and L_{1-3} BMD, the Pearson's correlation coefficients are 0.91 and 0.93 for women and men, respectively. We further analyzed the associations between L_{1-3} and any individual spine of T_1–L_5 and similar relationships were observed (*r* value, 0.62–0.98). The intraobserver, interobserver, and interscan variation measurement of thoracic quantitative CT was 2.5 (1.0, 95% CI 0.099–1.004); 2.6 (1.0, 95CI% 0.992–1.007), and 2.8% (1.0,95% 0.0994–1.008), respectively.

Conclusion: The 3T BMD was highly correlated with L_{1-3} BMD. Thoracic BMD can be measured during cardiac and lung CT imaging without need for additional participant burden or radiation dose. This highly reproducible methodology is actively being applied to large cohort studies to evaluate the prevalence of osteoporosis and track BMD over time.

Key Words: Bone mineral density; computed tomography; osteoporosis; quantitative computed tomography; coronary calcium scan.

Osteoporosis and coronary atherosclerosis are increasingly being recognized as coexisting conditions in an aging population. Computed tomography (CT), as a powerful tool for atherosclerosis diagnosis, obstructive coronary artery disease (CAD) evaluation, and cardiac events detection has seen significant increased utilization over the past 20 years (1). Quantitative computed tomography (QCT) measured lumbar bone mineral density (BMD) (2,3) is increasingly used for osteoporosis because of its ability to provide three-dimensional information compared to traditional dual x-ray absorptiometry two-dimensional images (4,5). Bone density evaluations have been performed with both phantoms and phantomless studies, and can be obtained whether contrast or noncontrast CT studies are obtained, by use of conversion factors (6–8).

Current 64-slice multidetector CT has been shown to be a feasible modality for providing improved cardiac imaging quality with decreased radiation doses (≤1 mSv) while simultaneously providing images of the thoracic spine. These studies provide the opportunity to study BMD during thoracic or cardiac imaging without additional radiation. If high correlation can be found in BMD measures between L_{1-3} and thoracic spinal imaging, it will allow thoracic BMD to be a potential screening tool for osteoporosis during acquisitions of other scans at no additional burden (except measurement time) (9–12).

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MATERIALS AND METHODS

Study Subjects

A total of 319 patients who underwent simultaneous thoracic and abdominal CT scans for clinical indications between January 2007 and June 2009 were enrolled. Nineteen cases were excluded from this study because of medications or conditions that can affect BMD and QCT BMD measurement, such as malignancies (two cases), status posthysterectomy (five cases), status post spine surgery (four cases), severe alcohol use (>3 ounces/per day, five cases), or renal insufficiency (serum creatinine ≥1.5 mg/dL or blood urea nitrogen ≥35 mg/dL, three cases). Finally, 300 cases (women, 49%) were used for data analysis. Another 389 patients who also underwent CT scans for coronary calcium (CAC) assessment were studied to assess reproducibility of three consecutive thoracic vertebra (3T) QCT remeasurements as validation data (Table 1).

Scan Technique

Thoracic and abdominal scanning. Using a 64-detector CT scanner (LightSpeed VCT, General Electric Medical System, Milwaukee, WI), a helical volumetric CT scan was completed for all subjects. A calibration phantom with unique extension cover from first thoracic spine (T_1) to fifth lumbar spine (L_5) at least was employed. The image included at least all vertebras between the seventh cervical and the sacral bone. The scan technique parameters were 120 kVp, automatic changeable current from 200 to 700 mA (using dose modulation), 0.516 pitch, 500 ms gantry rotation speed per revolution, and 5 mm reconstruction slice thickness. The isocenter was at the center of the chest and abdomen. The field of view size of reconstruction was 30–35 cm to allow inclusion of spine and calibration phantom completely.

CAC scanning. The coronary arteries were imaged with 30–40 contiguous 2.5-mm slices during mid-diastole using electrocardiogram triggering. The scan parameters were 120 kVp, 430 mA, and 350 ms/per rotation with 227 ms in temporal resolution. The calibration phantom had three plugs containing calcium hydroxyapatite (0, 75, and 150 mg/cm^3), and was 26 inches in length (Fig 1). Two QCT computers were used in this study: Q5000 and NVivo (Image Analysis, Columbia, KY).

Measurement and Analysis

In our study design, the left main (LM) coronary artery was set as reference site to allow reproducible detection of a spinal level for use with cardiac scanning.

The trabecular BMDs (mg/cm^3) from T_1 to L_5 and LM levels were measured and counted for all studies (Table 2). The thickness of the region of interest (ROI) was 6 mm. The center of ROI was located at the center of the vertebrae with a 2–3 mm distance from the spinal cortical bone. The cortical bone area, with large veins, bone islands, fractures as well as calcified herniated disks, were excluded as much as possible from the ROI by using the free tracing protocol.

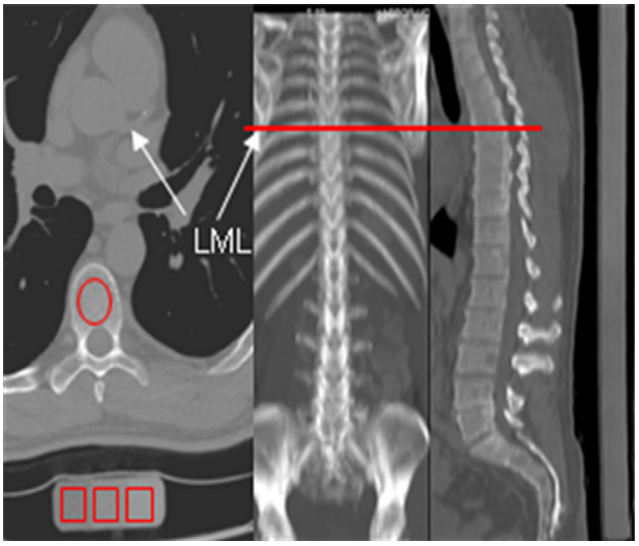

Figure 1. Measurement of bone mineral density (BMD) in 3T and 17 individual vertebrae by the QCT technique.

TABLE 1. Demographic Data Profile of 300 Subjects with Whole Body Scan

	Women (*n* = 147)	Men (*n* = 153)
Age, y	53 ± 8	57 ± 10
Height (cm)	162.9 ± 8.8	175.7 ± 9.1
Weight (kg)	66.4 ± 13.7	84.8 ± 16.4
Body mass index (kg/m^2)	25.0 ± 4.9	27.5 ± 4.9
Ethnicity		
Caucasian (%)	73 (49.7)	80 (52.3)
Hispanic (%)	34 (23.1)	29 (19.0)
African American (%)	11 (7.5)	13 (8.5)
Asia (%)	24 (16.3)	19 (12.4)
Other (%)	5 (3.4)	12 (7.8)

We chose to measure 3T to make comparisons to the more traditional measures of $L_{1\text{-}3}$. The mean value of 3T and $L_{1\text{-}3}$ were calculated for both genders and four age subgroups (Tables 3, 4). The Pearson's analysis was performed to evaluate the association between the BMD value of $L_{1\text{-}3}$ and each three consecutive vertebrae (with 1–12 representing T_1–T_{12}, and 13–17 representing L_1–L_5, respectively). We evaluated four thoracic groups that are available on cardiac CT studies as well as full lung scans ($T_{6\text{-}8}$, $T_{7\text{-}9}$, $T_{8\text{-}10}$, and $T_{9\text{-}11}$). $L_{1\text{-}3}$ was used as the comparison standard. The difference in BMD values between $L_{1\text{-}3}$ and each 3T from T_1–L_5 were computed using the following formula: (BMD of three consecutive vertebrae from T_1 to L_5 − $L_{1\text{-}3}$)/$L_{1\text{-}3}$ × 100%.

Assessment of Variability

Intraobserver variability of the thoracic BMD measurements was evaluating using 158 scans by one observer blinded to prior