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The distribution of bone mass in the lumbar vertebrae: are we measuring the right target?

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Abstract

BACKGROUND CONTEXT: The ideal target of bone mineral density (BMD) measurements of the spine is the trabecula-rich vertebral body. Yet, spine BMD measurements routinely obtained with dual-energy X-ray absorptiometry also include the posterior elements of the vertebra, which are mainly cortical bone and insensitive to bone loss.

PURPOSE: We compared the bone mass of the vertebral body and posterior elements to determine the contributions of vertebral components to vertebral BMD measurements.

STUDY DESIGN: A micro-computed tomography study of lumbar vertebral bone.

METHODS: From a spine archive, 144 cadaveric lumbar vertebrae (L1–L5) from 48 male human spines (mean age, 50 years) were scanned in air using micro-computed tomography to measure bone volume, bone mineral content (BMC) and BMD of the vertebral body, posterior elements, and entire vertebra. The contributions of the vertebral components to the total vertebral BMC and volume were compared, and the correlations between the BMC and BMD of the vertebrae and their components were examined.

RESULTS: Overall, the vertebral body contributed about one-third of the total vertebral BMC and two-thirds of the total vertebral volume, and the posterior elements contributed the remainder. The vertebral body BMC and BMD were poorly correlated to those of the posterior elements ($r=0.39$ for BMC and $r=0.34$ for BMD, $p<.0001$) and moderately correlated to the whole vertebra ($r=0.77$ and 0.75, respectively, $p<.0001$). The BMC and BMD of the posterior elements and whole vertebra were more strongly correlated ($r=0.89$ and 0.84, respectively, $p<.0001$).

CONCLUSIONS: The posterior elements are the primary contributor to vertebral BMC and BMD measurements. Dual-energy X-ray absorptiometry spine BMD measurements are likely to be more representative of the posterior elements than the targeted vertebral body. The findings elucidate the extent of the limitation of dual-energy X-ray absorptiometry spine BMD measurements.

Keywords: Lumbar spine; Vertebra; Osteoporosis; Bone mineral density; μCT; DXA

Introduction

Characterized by low bone mass and high fracture susceptibility [1], osteoporosis is one of the most common diseases affecting the elderly [2]. The medical costs for osteoporosis-related fracture, pain, and disability are enormous and continue to increase as the global population ages [2,3]. An accurate measurement of bone strength is central to any clinical decision making regarding osteoporosis. Yet, although bone strength is determined by both

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bone mineral density (BMD) and bone quality [4], it is BMD that serves as the primary surrogate and is used to assess for osteoporosis. New approaches such as trabecular bone score have emerged that may provide information related to microarchitecture; yet, the fundamental measure remains BMD.

Dual-energy X-ray absorptiometry (DXA) is routinely used in clinical practice; however, the accuracy and sensitivity of DXA in measuring BMD and predicting fracture are limited [5–7]. As a two-dimensional (2D) technique, it cannot capture 3D structure and true volumetric BMD (grams per cubic centimeter), but rather it captures areal BMD (aBMD, grams per square centimeter) that is a measure of all bone mass along the path of the X-ray projection. In the spine, this is particularly problematic because of the presence of spinal posterior elements that undoubtedly mask the changes in the primarily trabecular vertebral body. This is unfortunate because the vertebra is the most common site of osteoporotic fracture, with the prevalence of vertebral fracture rising rapidly with age and reaching as high as 50% among women older than 80 years [2,8]. The spine is also an important assessment site because it has been viewed as the best site to assess and monitor BMD for patients treated with corticosteroids [9]. Therefore, it is important to measure the spine as accurately as possible, which is usually applied at the L1–L4 lumbar vertebrae.

A vertebra consists of a vertebral body, which is rich in trabecular bone, and posterior elements, which are mainly cortical bone [10]. Bone loss first appears in skeletal sites that comprise largely trabecular bone with high turnover rates, such as the vertebral body. Therefore, instead of the whole vertebra, the main concern and the ideal target in spine BMD assessment is the vertebral body [11], which is primarily affected by osteoporosis and related fractures. Although the inclusion of posterior elements in spine BMD measurement is well recognized as a limitation of DXA [5,12], little is known about how the distribution of bone mineral content (BMC) in the vertebrae contributes to reduced sensitivity at this measurement site. A study recently investigated the contribution of posterior elements in the L3 vertebra in young subjects [13], but did not assess the entire vertebral body versus the posterior elements, and at more sites than L3.

The first objective of our study was to measure the BMC and volume of the vertebral body and posterior elements with micro-computed tomography (μCT) and determine regional contributions to the whole vertebra as a function of spinal level. A second objective was to explore the correlations between the BMC and volumetric BMD of the whole lumbar vertebra, vertebral body, and posterior elements to better understand the relative contribution of each volumetric region of the vertebra. Our measures based on volumetric BMD measured from μCT provide insight into what is being measured using an aBMD technique acquired from DXA.

Materials and methods

One hundred and forty-four intact cadaveric lumbar vertebrae from 48 adult, male human spines (mean age, 50 [range 21–64] years) were selected from a cadaver spine archive of Caucasian men [14]. The subjects died primarily from cardiovascular incidents and were without chronic illness, cancer, and infectious diseases. After routine autopsy, the vertebrae were dissected, dried, and then archived under room temperature and humidity.

All BMC and BMD measurements were obtained on a μCT system (XtremeCT; Scanco Medical, Brüttisellen, Switzerland). Vertebrae were scanned with a nominal isotropic resolution of 82 μm (field of view, 125 mm; 1,536×1,536 pixels; and integration time, 200 ms) in air. A total of 500 to 800 slices of axial vertebra μCT images were acquired for each vertebra. Then, regions of interest were identified and contoured using a semiautomated contouring method to include all bone tissues captured on each μCT slice and only the vertebral body (contouring along the conjunction of the vertebral body and pedicle). Finally, structure analyses were performed (Image Processing Language, v4.29d; Scanco Medical AG) to obtain the volume (cubic centimeter), BMC (milligrams of hydroxyapatite), and BMD (milligrams of hydroxyapatite per cm^3) for the entire vertebra, vertebral body, and posterior elements, respectively. In other words, the vertebral body and the posterior elements of each vertebra were radiologically separated after μCT 3D reconstruction (Fig. 1), and the corresponding measurements were acquired respectively. Micro-CT is a reliable radiological approach to quantify bone structural parameters and has been used as a "gold standard" for evaluating other bone densitometry techniques [15,16].

Descriptive statistics were used to determine the contributions of the vertebral body versus posterior elements to the total vertebral BMC and volume. The coefficient of variation (CV), which is the ratio of the standard deviation to the mean, was used to indicate the magnitude of the variability for the contributions of vertebral BMC and volume from the vertebral body. Pearson correlation coefficient was used to examine the correlations between the BMCs and BMDs of the vertebrae and their components. Linear regression was used to investigate the associations between the proportion of BMC and age and spinal level. Statistically significant results, defined as p value less than .05, were identified.

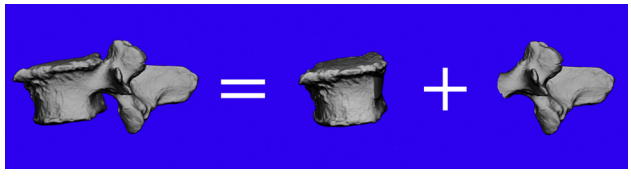

Fig. 1. Using micro-computed tomographic techniques, vertebrae were radiologically cut into vertebral body and posterior elements, and measurements were obtained for each independently.