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The osseous endplates in lumbar vertebrae: Thickness, bone mineral density and their associations with age and disk degeneration

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ABSTRACT

Introduction: As the gateway of nutrient supply, the vertebral endplate is essential to maintain the integrity and function of the avascular intervertebral disk. While a link between calcium deposition in the endplate and disk degeneration is well established from histological studies, findings on the association between endplate thickness and age and disk degeneration are conflicting. Moreover, the association between endplate bone mineral density (BMD) and disk degeneration remains unexplored in humans.
Objectives: To determine the thickness and BMD of lumbar spine osseous endplates in men and explore their associations with age and disk degeneration.
Methods: From a spine archive, 150 cadaveric lumbar vertebrae (L1–L5) from 48 male human spines (mean age 50 years, range 21–64) were scanned using micro-CT (μCT). The osseous endplates were extracted from the vertebral body to measure the mean thickness and volumetric BMD. The difference between cranial and caudal endplates, associations of endplate thickness and BMD with age and discographic degeneration pathology were examined.
Results: Overall, the mean thickness was 1.03 ± 0.24 mm for cranial (to disk) endplates and 0.78 ± 0.16 mm for caudal endplates. For lumbar intervertebral disks, the cranial endplate was significantly thicker and denser than the caudal endplate ($p<0.001$–0.05). Thickness and BMD of endplates were independent of age. Based on discography, a trend of more severe disk degeneration associated with greater thickness in both the cranial and caudal endplates was observed, and was most marked in severely degenerated disks ($p<0.05$). However, no evidence was detected for a link between more severe disk degeneration and elevated endplate BMD ($p>0.05$).
Conclusions: In the lumbar spine, both the thickness and BMD of endplates were independent of age, which ranged from 21 to 64 years. The endplates cranial to intervertebral disks were thicker and had higher BMD than the corresponding caudal endplates. Judged from discography, more degeneration in the adjacent intervertebral disk was associated with greater endplate thickness, but not higher endplate BMD. Thus, endplate sclerosis, reflecting elevated endplate BMD, may not be a risk factor for disk pathology in men.

Introduction

Consisting of cartilaginous and osseous components, the endplate is a thin layer of tissue located at the cranial and caudal ends of the intervertebral disk. During aging, the cartilaginous endplate undergoes progressive mineralization and eventually is resorbed and replaced by bone, leaving only the osseous endplate [1,2]. Virtually, the osseous endplate is the superior or inferior shell of the vertebral body, and thus, is also called the vertebral endplate.

Lying between the vertebral body and intervertebral disk, the endplate is essential to maintain the integrity and function of the intervertebral disk. Most importantly, the endplate is the gateway of nutrient transport between the vertebral marrow and intervertebral disk. While diffusion through the annulus supplies nutrients for the outer portion of the annulus [3], diffusion through the marrow contact channels in the vertebral endplate is the main nutrition pathway for the avascular intervertebral disk in adults [4–6]. On the other hand, the vertebral endplate also is a shield between stiff bone and resilient disk and serves as a mechanical interface. It not only prevents the highly hydrated nucleus pulposus from penetrating into the adjacent vertebral body [7], but together with the disk, it helps to distribute the compressive load evenly across the vertebral body [8].

Yet, the endplate is far less understood than the disk [9]. Scientific literature on structural features of the endplate, which might be

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important in maintaining the wellness of the intervertebral disk, such as thickness and bone mineral density (BMD), is sparse. Endplate thickness has been examined in a limited number of subjects and spinal levels, primarily by sampling several points in selected sagittal sections of the endplate and measuring local point-to-point thickness, with the reported mean thickness ranging from 0.35 to 0.95 mm [10–14]. Probably due to technical challenges, the overall mean thickness, which measures the entire endplate as a whole, has not been reported. Nor have studies been reported examining variations in endplate thickness across lumbar spinal levels. Also, despite a well established link between endplate calcification and disk degeneration from histological studies [4–7], with age-related endplate calcification thought to thicken the endplate [15], findings on the associations between endplate thickness and age and disk degeneration are conflicting [12,14,16]. In addition, although endplate sclerosis shown on radiographs, reflecting increased BMD resulting from endplate ossification, has long been regarded as a risk factor of disk degeneration, it was only quantified recently in a rodent model using dual energy X-ray absorptiometry (DXA) [17,18]. Despite a strong association reported between elevated endplate areal BMD and disk degeneration, supporting a role for endplate calcification in disk degeneration, the results are somewhat ambiguous due to the 2-dimensional basis of the DXA measurements. Moreover, the association between endplate BMD and disk degeneration remains unexplored in humans.

A better knowledge of the vertebral endplate structure and function would enhance understanding of the interaction between vertebra and disk and therefore, shed light on the pathogenesis of disk degeneration. The purposes of this study were to use micro-CT (μCT) to determine the thickness and BMD of lumbar vertebral endplates in men and explore their associations with age and disk degeneration. We hypothesized that greater thickness and BMD of the endplate, if resulting from an accumulation of calcification deposition during aging, would be associated with greater age. Further, we hypothesized that greater thickness and higher BMD of the endplate would impede the nutrient supply to the disk and thus, would be associated with more severe degeneration in the adjacent intervertebral disk.

Materials and methods

Subjects

We had access to a lumbar spine archive from 149 Caucasian male cadavers [19]. Subjects in the database passed away in the hospital wards or clinics. The inclusion criteria for this archive were men below the age of 64 years, who had been employed before death and whose history of illness or disease was short. Most of the subjects died from cardiovascular complications. Exclusion criteria were chronic illness or hospitalization and death from cancer or infectious diseases. Age, body weight and height were obtained at the time of death. Body mass index (BMI) (kg/cm^2) was calculated as weight divided by height squared.

Because some of the vertebrae and archived disk degeneration data in this spine archive were missing, only the vertebrae with available adjacent disk degeneration data were selected. Thus, 150 cadaveric lumbar vertebrae (L1–L5) and 209 adjacent intervertebral disks (L1/2–L5/S1) from 48 male human spines were included in the current study. The mean age for the sample is 50 years (range 21–64). The study was approved by the Health Research Ethics Board of University of Alberta.

Measurement of intervertebral disk degeneration

Disk degeneration was evaluated using discography after a routine autopsy examination of the lumbar spines [19]. Using a 20-gage needle and finger pressure, 2–5 ml Barium Sulfate (BaSO4) was injected anteriorly into the center of the intervertebral disk. All five intervertebral disks (L1/2 to L5/S1) were examined for each lumbar spine. Anterior–posterior and lateral X-ray radiographs were taken immediately after the injection of contrast. According to the spread or distribution of the BaSO4 in the discogram, a 4-grade ordinal scale was used to rate the degree of disk degeneration pathology. Disk degeneration was given a rating of none if the dye remained in the center of the disk; slight if the dye spread into the inner annulus; moderate if the dye spread from the inner to the middle region of the annulus; and severe if dye spread to the outer part of the annulus. Intraobserver agreement for measurements using this scale yielded a weighted kappa of 0.81 [19]. After discography, the soft tissues around the vertebrae were removed. Vertebrae were dried and then archived under room temperature and humidity.

μCT scanning and image processing

All thickness and BMD measurements were obtained on a μCT system (XtremeCT, Scanco Medical, Brüttisellen, Switzerland) using the standard manufacturer's in vivo parameters (60 kVp, 1000 μA, 200 ms integration time) [20].

The vertebra was axially scanned using μCT with a nominal isotropic resolution of 82 μm (field of view 125 mm, 1536×1536 pixels, integration time 200 ms). A total number of 500 to 800 slices of axial vertebra μCT images was acquired for each vertebra. Scans were performed in air.

The superior and inferior ends of the vertebral body were identified in the axial images, referring to the articular processes. At each end of the vertebral body, 20 to 40 axial slices (corresponding to 1.64 to 3.28 mm in thickness) were used to capture the osseous endplate tissues. Regions of interest (ROI) were identified and contours were drawn adjacent to the endosteal surface of the vertebral cortex shell on these selected images using a semi-automated contouring approach. ROI were filtered using a Laplace–Hamming filter and segmented using a global threshold.

An endplate consists of an epiphysial rim, which is the peripheral margin of the endplate near the vertebral body ring, and central endplate, which is the central portion of the endplate. The epiphysial rim is the place where the annulus fibrosus attaches and is relatively solid and impermeable compared with the thin and porous central endplate. It is well established that the central endplate is more important than the epiphysial rim in terms of nutrient supply [5,6]. With the aim of measuring the central endplate and avoiding the noise from osteophytes, all the endplate contours were shrunk 3 mm inward. Hence, the outer portion of the epiphysial rim (in the width of 3 mm) was not extracted for endplate 3-dimensional (3-D) image reconstruction (Fig. 1) and, therefore, was excluded from the thickness and BMD measurements.

As the ROIs contoured in the axial image of the vertebral body include cortical endplate and trabecular bone, a fully-automatic image analysis algorithm based on a dual threshold was applied to the ROIs to extract the cortical endplate and exclude trabecular bone. For all samples, the input thresholds of 3000 and 4000 were employed to ensure maximal consistency in segmenting the bone compartments. This technique is robust for segmenting cortical bone from trabecular bone and has been reported as highly reliable in extracting and measuring cortical bone [21]. The extracted endplate tissues were then 3-D reconstructed (Fig. 1) and all the 3-D endplate images were visually assessed to verify the quality of endplate extraction. If needed, ROI contours were adjusted to optimize the quality of segmentation.

Measurements of endplate thickness and BMD

A volume-based thickness analysis technique was employed to assess the overall mean thickness of the endplate, using the true 3-D images. This measure defines local thickness at a given point in the structure as the diameter of the largest sphere which includes the point and which can be fitted completely inside the structure [22]. As the thickness within an endplate varies at different sites, this method