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Variations in vertebral body dimensions in women measured by 3D-XA: A longitudinal in vivo study

S. Kolta [a,*], S. Kerkeni [a], C. Travert [b], W. Skalli [b], R. Eastell [c], C.C. Glüer [d], C. Roux [a]

[a] Paris Descartes University, Cochin Hospital, Rheumatology Department, Paris, France
[b] Arts et Metiers ParisTech , Laboratoire de Biomécanique, Paris, France
[c] Sheffield University, Northern General Hospital, Sheffield, UK
[d] Section Biomedical Imaging, Department of Diagnostic Radiology, University Hospital Schleswig-Holstein, Campus Kiel, Kiel, Germany

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ABSTRACT

Bone size and shape play an important role in bone strength, as shown by biomechanical testing and clinical studies. Vertebral body dimensions determine vertebral body strength even after adjustment for bone mineral density. We have recently proposed an in vivo method for 3D reconstruction of vertebral bodies using the whole spine imaging on a standard DXA device (3D-XA). The aim of our study was to measure in vivo vertebral body dimension changes by 3D-XA in women over a 6 year period. A total of 174 women were included in this study. They were divided into 3 groups: premenopausal (20–40 years; N = 53), postmenopausal women (55–60 years; N = 65) and elderly women (70–80 years; N = 56). Thoracic and lumbar spine (T4–L4) were reconstructed using the 3D-XA method at baseline and 6 years later. Biochemical markers of bone remodeling were measured at baseline. In premenopausal women, there was an increase in minimal cross-sectional area (minCSA), vertebral body volume as well as end plate width of the lumbar vertebrae, without statistically significant change of these parameters at the thoracic spine; there was no change in anterior heights. In postmenopausal women, there was a decrease in vertebral body anterior height and depth, driven by results in the elderly group at both the thoracic and lumbar spine. Vertebral body width decreased at the thoracic spine but increased at the lumbar spine. MinCSA and volume decreased at the thoracic spine, in contrast with an increase of these 2 parameters at the lumbar spine in early postmenopausal women (55–60 years). In elderly women (70–80 years), the change in minCSA and volume of the lumbar spine was not statistically significant over 6 years. In postmenopausal women, there was no correlation between changes in vertebral dimensions and baseline biochemical markers of bone remodeling except for NTX/Cr and anterior height decrease. Our study confirms that an increase in geometric dimensions of lumbar vertebrae occurs through adult life. This could be related to a compensation for bone loss, aiming to maintain bone strength through increase in size. However, this phenomenon is not observed at all levels in the spine; since we do not confirm this increase at the thoracic spine. This might be one of the determinants of the higher risk of fractures in this part of the spine.

Introduction

Bone size and shape play an important role in bone strength, as shown by biomechanical testing and clinical studies. Most of the studies have been conducted at the hip, showing that geometric parameters (femoral neck width, hip axis length, femoral shaft diameter, femoral head diameter, …) are contributors to the hip fracture risk [1–3]. Increase in the appendicular bone dimensions, including the femur, is an age-related phenomenon that could be aiming to compensate for reduced bone mineral density (BMD) by increasing cross-sectional area through endosteal resorption and periosteal apposition with thinning of the cortex [4,5]. Vertebral body size is also a potential determinant of vertebral body strength, but few studies have examined the role of vertebral geometry on fracture risk. A systematic literature review found 13 studies focusing on the differences in vertebral body geometry between patients with vertebral fractures and non-fracture controls; a total of 4426 women and 508 men were assessed (mean age 64 years). On average, cross-sectional area (CSA) and volume of vertebral bodies were 7.7% and 9.5% smaller in subjects with fractures [6], suggesting that small vertebral dimensions contribute to the development of vertebral fractures. Clinical studies [7] and biomechanical tests [8] performed on human vertebrae have previously shown that both bone mineral density (BMD) and dimensions determine vertebral body strength. Cross-sectional studies have suggested that age related changes of dimensions occur at the vertebrae, as at peripheral bones, with on average 14% higher CSA of lumbar vertebrae in older than in younger women [9,10]. Putting in perspective the apparent increase in area and the decrease in density with age is an approach to explain the difference in fracture risk among individuals

* Corresponding author at: Cochin Hospital, Rheumatology Department, 27, rue du faubourg Saint Jacques, 75014 Paris, France. Fax: +33 1 44 07 01 07.
E-mail address: sami.kolta@cch.aphp.fr (S. Kolta).

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and gender [11]. Only two studies assessed prospectively vertebral body dimensions: parameters were measured on lateral radiographs in a total of 2017 postmenopausal osteoporotic women (aged 73 ± 6 years) followed 3 years and receiving calcium and vitamin D supplementations. There was a significant increase in vertebral body depth, area and perimeter [12]. In another prospective study in patients on teriparatide treatment measurements by high resolution CT showed the feasibility of this technique to assess submillimeter changes in vertebral dimensions with a precision error below 1%. The authors report a small significant increase by 0.9% ($p<0.0001$) over two years which may in part be treatment related [13].

The gold standard for measuring bone dimensions is computed tomography (CT), which is however limited to the lumbar spine, or even L3 [9–11] for radiation concerns. Estimation of vertebral body dimensions using two-dimensional (2D) techniques such as x-rays, is subject to errors and approximations: to calculate vertebral body volume, the shape must be calculated as a cube [14], a cylinder [15] or an ellipsoid cylinder [16]. We have recently proposed a method for 3D reconstruction of vertebral bodies using the whole spine imaging on a standard dual energy X-ray absorptiometry (DXA) device [17]. This technique, the 3D-XA (for 3-dimensional X-ray absorptiometry) allows a 3D measurement of vertebral body geometric parameters, including height, depth, width, CSA and volume with very low radiation to the patient, and is achievable at the time of BMD assessment.

Using this 3D-XA method, our study aimed to measure vertebral body dimension changes in women over 6 years. By studying the whole spine in pre- and postmenopausal women, we aimed to assess any difference in these changes according to age and spinal level.

Subjects and methods

Subjects were women participating in the OsteoPorosis and Ultrasound Study (OPUS) using data collected in 2 of the 5 centers which have the same type of device (for 3D calibration purposes). **A**ppropriate ethical approval and written consent were obtained from all participants in the OPUS study. The women participating at the OPUS study were selected from the general population using registers of a complementary health insurance system [18]. They answered a questionnaire on general health, medications, medical history and fractures. Vertebral fracture was assessed at baseline and 6-year visits, using the vertebral fracture assessment (VFA) software for premenopausal women and spine radiographs for postmenopausal women. Spine radiographs from all the centers participating in OPUS study were centrally assessed. None of the patients included in our study had a prevalent or incident vertebral fracture. All participants had a posterior-anterior (PA) and lateral images of the spine using the VFA software on a standard Hologic QDR 4500A device (Hologic Inc, Bedford, MA) equipped with a C-arm, allowing the acquisition of two orthogonal scans (PA and lateral views) with the patient in the supine position without any movement between the two scans. VFA scans were acquired using the single energy mode of scan. These images of 40 cm length allowed visualisation of the thoracic and lumbar vertebrae were acquired at baseline and 6 years later on the same device. Bone mineral density (BMD, g/cm²) was measured at the spine and hip (femoral neck and total hip). Three groups of patients were included in this study: premenopausal (20–40 years), postmenopausal women (55–60 years) and elderly women (70–80 years). The whole population in the 2 centers (Kiel and Paris), in the 3 age-groups of our study and who attended the 6-year visit were 455 subjects. We excluded patients having prevalent or incident vertebral fracture (according to the central reading center), non-vertebral fracture (self-reported by the patient, and verified whenever possible by radiographs or medical reports): N = 84. We also excluded patients who received glucocorticoids on regular basis for chronic inflammatory diseases such as rheumatoid arthritis and patients suffering from malignant disease at baseline and follow-up visits. The VFA scans of the remaining patients were checked for quality allowing a good visualization of the vertebral contours on both PA and lateral views. Scans with severe scoliosis or osteoarthritis or with several unreadable vertebrae were excluded. We did not aim to do the reconstruction of the whole OPUS population. Our aim was to get about 30 patients from each center for each age group. Roughly, we can estimate VFA scans of bad quality (due to severe scoliosis or osteoarthritis or severe obesity, …) that would preclude 3D reconstruction about 10–20% of our scans.

Calibration of the DXA device environment was performed using a Plexiglas box with small metallic beads with known 3D coordinates fixed on it [19]. This box was scanned on the same DXA device used in this study. The 3D reconstruction of vertebrae using 3D-XA method was performed according to our previously published methodology [17]: DXA scan images were used for the reconstruction using a custom software package, developed in collaboration between the Laboratoire de Biomécanique, Arts et Métiers ParisTech, Paris, France and the Laboratoire de recherche en Imagerie et Orthopédie, Montréal, Canada. This method is easily applicable to vertebrae if the projections of the limits of the vertebral bodies are clearly identifiable on both PA and lateral images [20,21]. Briefly, a first estimate of the vertebral geometry is built by 3D deformation of a generic model based on spinal curves. This model is adjusted to the contours of the radiograph by the operator. During the process, the model is improved by multi-linear regression on the 19 control points used for the deformation method. The 3D reconstruction of the vertebral body was performed from both DXA images by the operator avoiding osteophytes and spurs, in order to delimit vertebral body anatomy, and excluding osteophytes. In a further interactive step, the operator improves the geometric details of the 3D reconstruction that was proposed by the software, to best adapt it to the radiological projections. At this stage, the 3D reconstruction of the different vertebrae is achieved (Fig. 1). The time spent to do the 3D reconstruction of the whole spine (N = 13 vertebrae, from T4 to L4) was about 10 min. For a non-experienced person, it takes about 20 min.

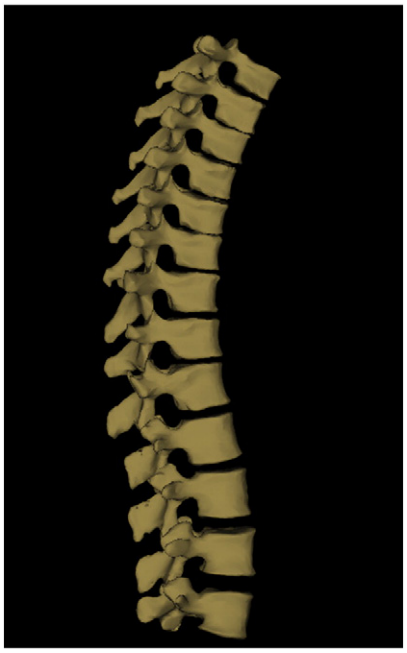

Fig. 1. In vivo 3D reconstruction of T4–L4 human vertebrae by the 3D-XA method.