Original Article

Distribution of Bone Mineral Density in the Lumbar Spine in Health and Osteoporosis

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Abstract. The significance of variability in bone mineral density (BMD) between lumbar vertebrae L1 to L4 in the same individual was investigated by dual-energy X-ray absorptiometry in 1000 normal women aged 40-60 years (average 52 years) and 145 women aged 45-80 years (average 65 years) with vertebral osteoporosis. The mean BMD increased from L1 to L4 in normal women from 0.841 g/cm² to 1.017 g/cm², and in osteoporotics from 0.562 g/cm² to 0.709 g/cm². Z scores for osteoporotic women (Z = osteoporotic BMD - age-normal BMD/normal SD) were significantly lower for individual vertebrae compared with L1-4 and at L4 compared with L1, L2 and L3 (p < 0.001). The mean difference between Z scores for the highest and lowest vertebrae in an individual was 0.70 for normals (SD = 0.40) and 0.64 for osteoporotics (SD = 0.36). The mean Z score difference between the L1-4 Z score and the lowest individual vertebral Z score was 0.36 for normals (SD = 0.23) and 0.06 for osteoporotics (SD = 0.31). However, receiver operating analysis (ROC) curves showed that the lowest Z score for any individual vertebra did not provide improved discrimination between normals and osteoporotics when compared with the L1-4 Z score. The area under the ROC curve for L1-4 was significantly greater than for individual vertebrae (p < 0.05) and that for L4 was significantly smaller than for L1, L2 or L3 (p < 0.001). In conclusion, L1-4 BMD gives greater diagnostic sensitivity for osteoporosis than individual vertebrae, and L1, L2 and L3 are better than L4. Although there is considerable individual variation in Z scores for different vertebrae in the same individual, the lowest vertebral Z score does not offer improved diagnostic sensitivity over the L1-4 Z score.

Keywords: Bone mineral density; DXA; Osteoporosis; Spine; Vertebrae

Introduction

It is usual in clinical practice and research to present lumbar spine bone mineral density (BMD) as averaged values over L1-4 or L2-4. However, this method of calculating BMD may mask large variations in measurements at individual vertebrae. Indeed in a recently reported study a difference in BMD of 25% between the lowest and highest vertebrae between L2 and L4 was found in 11% of 236 normal women aged 36-85 years [1]. A normal spinal BMD averaged over several vertebrae may underestimate the risk of fracture in an individual if one or more individual vertebrae have low BMD values, although there is no information available at present to support this. It is therefore possible that consideration of each spinal vertebra separately may allow a more accurate assessment of the individual than an averaged spinal measurement over several vertebrae.

It is also well recognized that there is an overlap in BMD of normal and osteoporotic women [2], with some studies demonstrating that vertebral fractures are no better predicted by spinal BMD than by measurement at the femoral neck or at peripheral sites [3,4]. However, it is possible that the lumbar vertebrae vary in their ability to separate osteoporotics from normals. Selection of the vertebrae with the best diagnostic sensitivity could therefore improve the usefulness of the...
Materials and Methods

Lumbar spine BMD measurements were made from L1 to L4 by dual-energy X-ray absorptiometry (DXA) using the Hologic QDR 1000 or QDR 2000 in 1000 normal women aged 40–60 years (average 52 years) and 145 osteoporotic women aged 45–80 years (average 65 years) and reviewed retrospectively. The normal women were consecutive referrals from their General Practitioners in London and the South-East of England for measurement of their bone density to assess their risk of osteoporosis. Women with established risk factors or secondary causes for osteoporosis were excluded. The exclusion criteria were fractures sustained after the age of 25 years, a menopause before 40 years, secondary amenorrhoea of more than 6 months duration, non-Caucasian, use of hormone replacement therapy for more than a year, and chronic medical conditions affecting bone density such as rheumatoid arthritis, thyrotoxicosis and diabetes mellitus. The osteoporotic women were consecutive referrals to a specialist osteoporosis clinic who did not have known secondary causes. Radiographs were not performed on these normal women.

Vertebral collapse was established in the osteoporotic individuals from the presence of wedge, biconcave or compression fractures as defined by the method of Eastell et al. [5]. Anterior (ha), middle (hm) and posterior (hp) heights of vertebrae were measured. From these values wedge deformities were defined from (hp - ha)/hp × 100, biconcave deformities from (hp - hm)/hp × 100 and compression deformities from (hp' - hp) × 100 where hp' is the posterior height of an adjacent vertebra. Abnormal vertebrae were those where one of the above measurements were > 3 SD from normal values. Measurements defining normal vertebrae were derived from 50 normal women aged 40–65 years without radiological evidence of spinal fracture or a history of fractures that may affect bone mass and who had normal bone densities for their age.

Precision in vivo was estimated by same-day measurements on 16 normal women, with the coefficient of variation (CV) being derived from the root mean square of the results [6]. For the 1000 normal women, mean BMD and standard deviation was obtained for each lumbar vertebra and over all four vertebrae L1–4. The same measurements were made on the osteoporotic women, only unfractured vertebrae being included in the analysis. The fracture thresholds were calculated as the 90th centiles of BMD from the osteoporotic patients. The significance of differences between the BMD of individual vertebrae was assessed by the paired student’s t-test on individuals’ paired differences.

Z scores were obtained at lumbar vertebra from L1 to L4 separately and combined for normals and osteoporotics, where Z = (BMD - age-normal BMD/normal SD). The mean and SD were calculated for the Z scores and statistical differences again compared by paired Student’s t-test. The mean and SD of the highest and lowest Z scores for the four lumbar vertebrae in both normals and osteoporotics were also calculated. The age-normal BMD values for calculation of Z scores were obtained from the Hologic database for North American women, which had previously been shown to not differ from our normal range over ages 40–60 years [7]. It was used for the normal range because of the greater numbers of subjects over 60 years compared with our normal data.

For both normal and osteoporotic women simple linear regression analysis was performed comparing individual vertebrae with each other and with groups of lumbar vertebrae, and correlation coefficients and standard errors of the estimate (SEE) obtained. Receiver operating analysis (ROC) curves were generated for comparing the ability of Z scores in individual vertebrae, L1–4 and the lowest Z score of any of the four vertebrae to separate normals and osteoporotics. The areas under curves were compared for significant differences by the method of Hanley and McNeill [8].

Results

The coefficients of variation were: for L1 BMD, 2.4%; for L2 BMD, 1.1%; for L3 BMD, 1.5%; for L4 BMD, 1.6%; and for L1–4 BMD, 0.81%. In Table 1 the mean and SD for normal women are given both for individual lumbar vertebrae and for the region L1–4. Analysis of pairwise differences in BMD at different lumbar vertebrae showed an average difference between L1 and L2 BMD of 0.095 g/cm² (SD 0.060, p < 0.001), between L2 and L3 BMD of 0.048 g/cm² (SD 0.059, p < 0.001) and between L3 and L4 BMD of 0.033 g/cm² (SD 0.074, p < 0.001). The same measurements together with calculation of the fracture thresholds were made on the osteoporotic women (Table 2), but including only vertebrae that were not collapsed (< 3 SD below normal mean, based on radiological results). The average difference between L1 and L2 BMD was 0.070 g/cm² (SD 0.079, p < 0.001), between L2 and L3 BMD was 0.052 g/cm² (SD 0.077, p < 0.001) and between L3 and L4 BMD was 0.026 g/cm² (SD 0.113, p < 0.01).

The mean and SD of Z scores for individual vertebrae, L1–4 and lowest and highest Z score at any one vertebra are given in Table 3. There was no significant difference (p > 0.05) in the mean Z scores of the lumbar vertebrae in normals, but in osteoporotics although L1, L2 and L3 were comparable the score for L4 was significantly (p < 0.001) lower. Furthermore, L1–4 had a greater Z score than all the individual vertebrae (p < 0.05).

Simple linear regression for BMD between individual vertebrae showed highly significant correlation coefficients (Table 4), although values were lower for the osteoporotic women. High correlation coefficients were