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The effect of vertebral rotation of the lumbar spine on dual energy X-ray absorptiometry measurements: observational study

腰椎脊柱的脊椎骨旋轉對雙倍能量X光吸收測量的影響：觀察性研究

Objective. To estimate how axial rotation of lumbar vertebrae quantitatively affects bone mineral density, as measured by dual energy X-ray absorptiometry in the anteroposterior plane.

Design. Observational study.

Setting. University teaching hospital, Hong Kong.

Patients. Cadaver lumbar vertebrae (L2 to L4) were removed from four adults.

Main outcome measures. Using dual energy X-ray absorptiometry, the bone mineral content, bone area, and bone mineral density were measured in the neutral position and with vertebral axial rotation in increments of 7.5 degrees, up to a maximum of 45 degrees.

Results. Correlation analysis showed a significant positive correlation between the degree of rotation and measured bone area, a significant negative correlation between degree of rotation and bone mineral density measurements, but no significant correlation between degree of rotation and measured bone mineral content. The measured bone area increased approximately 24% and the bone mineral density decreased approximately 19% when the vertebrae were rotated by 45 degrees.

Conclusions. These results suggest that for patients with rotational deformity of the spine, such as scoliosis, measurements of lumbar spine bone mineral content by dual energy X-ray absorptiometry is not affected, while bone mineral density measurements are not reliable.

目的：評估利用雙倍能量X光量度腹背面吸收量時，腰椎骨的軸向旋轉對骨礦物質密度的影響量。

設計：觀察性研究。

安排：香港，大學教學醫院。

患者：四名成人屍體的腰椎骨(L2 至 L4)。

主要結果測量：以7.5度為增加量，對中位和脊椎施以軸向旋轉，直至最大45度時，使用雙倍能量X光吸收測量計量度骨礦物質含量，骨面積和骨礦物質密度。

結果：相關性分析顯示旋轉度和骨面積之間有顯著的正比關係，而旋轉度和骨礦物質密度之間有顯著的反比關係，但旋轉度和骨礦物質含量之間關係並不重要。當旋轉達 45 度時，所量度的骨面積增加約 24% ，而骨礦物質密度減少約 19% 。

結論：這些結果顯示，對於患有諸如脊柱側凸的脊骨轉動殘障的病人，用雙倍能量X光吸收測量計進行量度時，骨礦物質含量讀數不受影響，但骨礦物質密度讀數並不可靠。

Key words:
Absorptiometry, Bone density;
Densitometry, X-ray;
Lumbar vertebrae;
Scoliosis

關鍵詞：
吸收測量，骨密度；
密度測量學，X 光；
腰椎骨；
脊柱側凸

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Introduction

One of the limitations of dual energy X-ray absorptiometry (DXA) is that it projects the three-dimensional bone structure into a two-dimensional image.[1] Measured bone mineral density (BMD) in the spine is thus likely to be affected by any axial rotation of the vertebrae, because of its irregular shape. Although scoliosis describes the lateral curvature of the spinal column, it is known to be associated with rotational deformities and axial torsion. The degree of rotation is commonly estimated by the Nash-Moe method, using plain anteroposterior (AP) radiographs of the spinal column.[2,3] To date, however, there have been no studies completed correlating the degree of rotation with BMD measurement of the lumbar spine. Vertebral rotation may potentially affect the diagnostic sensitivity of quantitative bone densitometry for patients with rotational deformities of the spine. During longitudinal follow-up of patients, progression of rotational deformity may further affect the assessed bone mineral status of a given individual. Consequently, this study undertook bone mineral measurements using DXA on cadaver lumbar vertebrae. The aim was to estimate the quantitative effect of rotation of the vertebrae on bone mineral content (BMC), bone area and BMD measurements in the AP plane.

Methods

Cadaver lumbar vertebrae, including the L2-L4 segment, were removed from four adults (two males and two females) aged 17 to 40 years. Ideally, specimens would have been obtained from adults aged between 30 and 40 years, the age at which bone mass has reached peak value, and when degenerative changes are still insignificant. This, however, is difficult to achieve in practice. The specimen used from the 17-year-old participant was readily identified as an adult specimen, as the ring apophysis was completely fused to the vertebral body, signifying the completion of vertebral growth. Dual energy X-ray absorptiometry measurement was completed shortly after autopsy. All soft tissue was removed, and the facet joints of the vertebral segments were glued together to stabilise the segments. A plastic stand (Fig 1a) was specifically developed for positioning the specimens. Both posterior tips of the L4 facets were placed in contact with the vertical part of the plastic stand. Rotation of the vertebrae was determined by the line of the spinous process to anterior midpoint of the vertebrae in relation to the vertical axis (Fig 1b). The angle of rotation in 0 degrees, that is, true AP projection, was achieved by lying the L2 to L4 vertebral bodies horizontally on the plastic stand. Dual energy X-ray absorptiometry was performed using a Norland XR-26 dual energy X-ray densitometer (Norland Medical System, Inc., Wisconsin, US) and software comprising version 2.5.0 for research scanning (Norland Medical System, Inc., Fort Atkinson, Wisconsin, US) giving a resolution of 1.0 mm x 1.0 mm, at a speed of 30 mm/s. Since adjacent vertebrae are connected with each other via facet joints, the calculation of L2 to L4 BMD in vivo includes the overlapping distal part of L1 and the proximal part of L5. Hence, in this study,

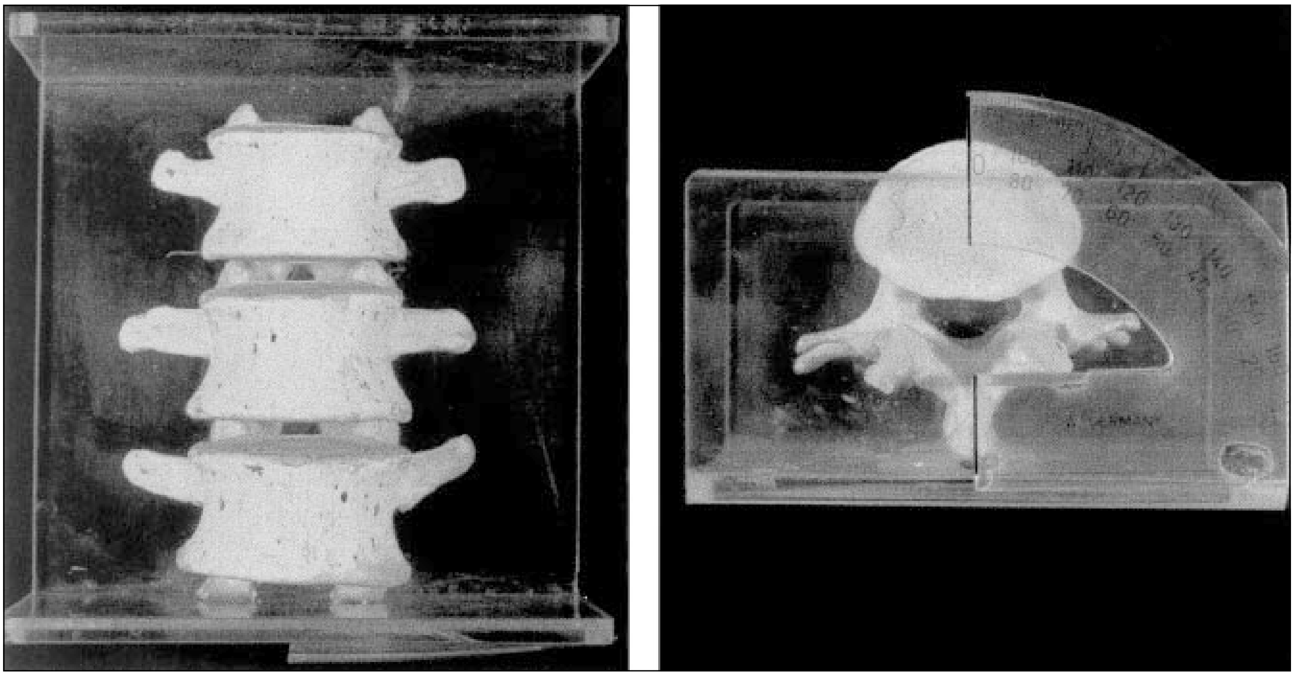


Fig 1. (a) The plastic stand designed for positioning of vertebrae; and (b) rotation of the vertebrae is determined by the line of the spinous process to anterior midpoint of the vertebrae in comparison to the vertical axis

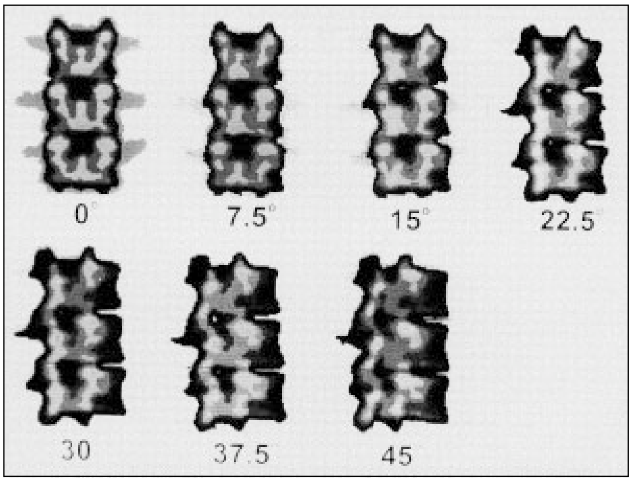


Fig 2. Dual energy X-ray absorptiometry measurements for the neutral position and for vertebral axial rotation in increments of 7.5 degrees per scan, up to 45 degrees rotation

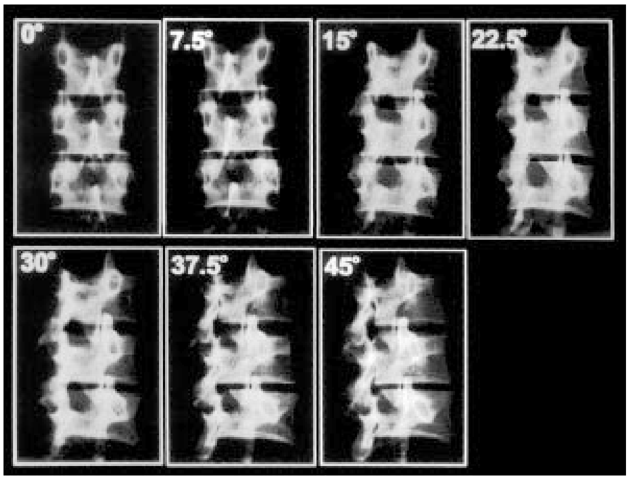


Fig 3. Plain radiographs showing vertebrae rotated by 7.5 degree increments, up to 45 degrees rotation

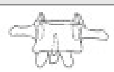
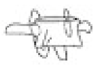
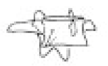
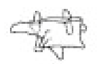
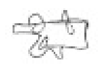
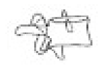
the whole length of L2 to L4 was scanned, and the DXA measurements of L3, including BMC, bone area and BMD, were recorded for the neutral rotation position first, followed by consecutive measurements, with vertebral axial rotation in increments of 7.5 degrees up to 45 degrees rotation (Fig 2). The entire set of DXA measurements for each neutral and oblique position was repeated six times for each set of vertebrae. Average measurements were recorded to minimise the influence of technical error on the results.

With the same plastic stand, plain radiographs in the AP plane were also taken for the vertebrae in different positions, again in increments of 7.5 degrees rotation, from 0 to 45 degrees (Fig 3). Nash-Moe classification of the degree of spinal rotation on the plain radiographs was completed (Table 1).[2,3] Nash-Moe classification is based on the AP projection of the spine, using the symmetry of the pedicles as the point of reference. Migration of the pedicles towards the convexity of the curve is used to determine the degree of vertebral rotation (Table 2).[2,3]

Statistical analysis

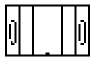
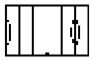
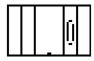
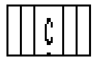
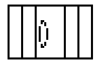
The mean and coefficient of variation for DXA measurements of each neutral and rotational position were calculated. Using the DXA measurements, with neutral position as the baseline value, the percentage of the baseline value was calculated for each rotational position. Pearson correlation analysis was used to evaluate the relationship between degree of axial rotation of the vertebrae and BMD measurements.[4]

Table 1. Measurement of bone area, bone mineral content, and bone mineral density for L3 in each position

Degree of rotation	Nash-Moe index	Outline of L3 vertebra	Measured area (cm^2), cv* (%BLV)†	Bone mineral content (g), cv (%BLV)	Bone mineral density (g/cm^2), cv (%BLV)
0°	0		12.96, 9.33% (100%)	12.36, 13.83% (100%)	0.95, 9.31% (100%)
7.5°	I		13.16, 8.83% (101.5%)	12.37, 13.84% (100.1%)	0.94, 8.48% (98.9%)
15°	I		13.45, 8.60% (103.8%)	12.38, 13.74% (100.2%)	0.92, 8.57% (96.8%)
22.5°	II		14.24, 6.76% (109.9%)	12.39, 13.18% (100.2%)	0.87, 10.46% (91.6%)
30°	II		14.74, 6.32% (113.7%)	12.38, 13.04% (100.2%)	0.84, 10.84% (88.4%)
37.5°	III		15.38, 6.38% (118.7%)	12.42, 12.93% (100.5%)	0.81, 10.48% (85.3%)
45°	III		16.07, 7.20% (124.0%)	12.38, 12.85% (100.2%)	0.77, 9.55% (81.05%)

* Mean, coefficient of variation (coefficient of variation=[standard deviation/mean] x 100%)
† Percentage of baseline value

Table 2. Nash-Moe pedicle method for determining vertebral rotation

Vertebral rotation	0	I	II	III	IV
Presentation in anteroposterior X-ray	 Pedicles symmetrical	 Left pedicle disappearing	 Left pedicle disappears	 Right pedicle in centre	 Right pedicle crossing midline

Statistical significance was considered to be reached at P<0.05. StatXact 4 (Cytel Software Corporation, Cambridge, US) was used for all statistical analyses.

Results

The mean value, coefficient of variation, and percentage of baseline value for DXA measurements of L3 in each position are reported in Table 1.

The degree of rotation correlated significantly with the bone area and BMD measurements (both P<0.001), whereas the BMC was not correlated with the degree of rotation (P=0.966). The correlation was positive for bone area (r=0.747; 95% Confidence interval [CI], 0.589 to 0.905; P<0.001), but negative for BMD (r=-0.655; 95% CI, -0.847 to -0.463; P<0.001). The DXA measurements were converted into a percentage by taking the DXA measurements at the neutral rotation as a baseline value of 100%.

Discussion

Degenerative changes, such as osteophytes, vascular calcification, and osteochondrosis in ageing people have been found to result in false high BMD measurements.[5] There is currently a lack of studies quantifying the relationship between BMD measurement error and the degree of axial rotation. This study has shown that axial rotation of the spine can cause significant variation in the measured bone area and BMD value of the lumbar spine. Only minimal variation in BMC occurred during axial rotation of the vertebrae. During rotation, BMC of the vertebral body would not be expected to change, since the whole vertebral body is included in the projectional area regardless of rotational position. What is changed is the component of the transverse processes and the posterior column included. Since some parts of the posterior and lateral elements are rotated into the projectional area, however, whereas other parts are rotated out of it, there is no significant variation in BMC according to rotational position. In contrast, the bone area increases with rotation and leads to a falsely low BMD, since BMD is calculated as the ratio of BMC to the projected bone area.

Axial rotation is very commonly associated with the deformity of scoliosis.[6,7] Axial rotation of the vertebrae in scoliosis is commonly graded clinically according to the Nash-Moe classification.[2,3] Results of this study demonstrate that errors in DXA measurements occur in relation to the position of rotation, as graded by the Nash-Moe classification. With significant rotation of the lumbar spine in scoliosis (axial rotation of 45 degrees), the AP BMD measurement can be 19% lower than the BMD measurement in the neutral position. Bone mineral density is calculated from the ratio of the total BMC to the detectable bone area. Results of this study indicate that the bone area of a vertebra in an AP projection is smaller than in any oblique projection. Most of the posterior elements of a vertebra are obscured behind the vertebral body in the AP projection. An oblique position, for example due to axial rotation, however, increases the projected area, since portions of the laminae, the pedicles and the spinous process cause a progressive increase in the bone area, according to the degree of axial rotation (Figs 2 and 3).

In clinical practice, it is difficult to position the patient with scoliosis to allow exact correction of the error of measurement introduced by rotational deformity. It is also difficult to predict the progression of rotational deformity, since the spinal rotation's relationship to angular deformity in scoliosis has not been properly documented. It is generally true that the more severe the curve, the greater the rotation. When a large series of cases of mixed severity were studied, however, it was noted that the relationship was far from linear, with many patients having large curves and little rotation.[2] Previous studies using computed tomography have shown that the torsion deformity of the vertebrae itself does not occur in curves with Cobb's angles of less than 40 degrees.[7] In severe scoliosis (with curves of more than 40 degrees), there is considerable torsional deformation within a given vertebra—the vertebral body, the laminae, the pedicles, the spinous process, and the transverse processes may be asymmetrical.[8] Thus, not only the rotation of the spinal column but also the torsional deformity in the vertebrae can interfere with the diagnostic sensitivity and longitudinal follow-up of DXA measurements in these patients, if using BMD as an evaluation parameter. Previous studies of BMD measured by DXA, demonstrated significantly lower BMD measurements in the lumbar spine of patients with adolescent idiopathic scoliosis than in the lumbar spine of healthy adolescents.[9,10] The influence of the axial rotation of the scoliotic spine on the BMD in the lumbar spine region was not discussed. A previous study by the authors queried this finding.[11] Rand et al[5] investigated the impact of spinal degenerative changes on the evaluation of BMD of the lumbar spine by DXA, in patients with a mean age of 63.3 years. They found that scoliotic changes had no effect on the BMD value in the lumbar spine, whereas osteophytes, osteochondrosis, and vascular calcification resulted in significantly higher BMD measurements. The degree of scoliotic deformity and other associated degenerative changes in scoliotic subjects investigated was not reported.

For BMD measurement of patients with scoliosis, the recently recommended lateral spine scan using DXA, does not eliminate the influence of rotation of the vertebrae. The lateral spine scan measures only the BMD of the vertebral body, without involvement of posterior elements.[1] In scoliotic subjects, however, vertebral rotation may result in incorporation of posterior elements (which have more cortical bone) into the projected area, thus leading to a false elevation in measured BMD.[12]

Conclusions

In the assessment of bone mineral status for patients with scoliosis, DXA BMC of the lumbar spine is a reliable parameter. Bone mineral density of the lumbar spine, in contrast, should be interpreted critically due to artifacts arising from the axial rotation of the spinal column. During BMD follow-up studies, consistent positioning of patients with the same rotation of the spinal column could be a means of reducing error due to vertebral rotation, facilitating the collection of reproducible findings.

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