Axial Rotation Significantly Affects DXA Lumbar Spine BMD Measurements

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Introduction
To determine bone mineral density (BMD), dual energy X-ray absorptiometry (DXA) is commonly used to measure the areal density of three dimensional bone structures. BMD is normally measured in clinically important bones such as the lumbar spine or femoral neck and the measurements are standardised. For each anatomical site it is essential to provide clearly recognisable structures and good reproducibility to establish normal reference ranges. A patient’s BMD is compared to the standard reference ranges, and it is therefore essential for DXA imaging procedures to conform to these standards. However, it is not always possible to control for anatomical variations or axial rotation from the ideal orientation. A number of studies have demonstrated the effect in the femoral neck of varying internal rotation but there has been little discussion of the effect in the lumbar spine.

The aim of the study was to assess the degree to which axial rotation affects BMD measurements in a simple lumbar spine phantom and an anthropomorphic lumbar spine phantom.

Materials and Methods
All scans were performed on a GE-LUNAR Prodigy Vision (DF = 1.3727, software version 9.15) using standard Spine software.

Figure 1a shows the custom made rotation cradle used with a GE-Lunar Aluminium spine phantom (GE-LASP). The phantom was scanned 5 times each at 0º, 5º, 10º, 20º, 30º and 45º from horizontal in a 15cm water bath. A Hologic Anthropomorphic spine phantom (figure 1b) was scanned 5 times each at 0º, 5º, 10º, 20º, 30º, 45º, 60º and 90º from horizontal, using wedges at each corner or a lab jack to elevate the phantom to a trigonometrically calculated height corresponding to the required angle at the height measured with digital callipers prior to scanning. A forearm positioner was used to ensure the phantom was square with the long axis of the bed in each scan. For each phantom, the BMD of L1-L4 was determined using standard spine analysis. Average BMD and area measurements at each angle were determined from the extracted scan data.

Due to the varying density of spinous processes as the phantom was rotated, the Hologic Anthropomorphic spine phantom bone edges were analysed with either spinous processes included (processes) or excluded (no processes).

Theoretical projected areas for each angle of the GE-LASP were calculated by applying trigonometric principles to the physical dimensions of the phantom measured using digital callipers. Theoretical BMD for each angle was then calculated using the observed BMC at 0º and trigonometrically projected areas by applying:

\[ \text{BMD} = \frac{\text{BMC}}{\text{Area}_{\text{geo}}} \]

The resultant BMD was compared to the actual BMD for each angle and the average percentage change calculated. Average and standard deviation were calculated.

Statistical Tests
The effect on BMD was examined by calculating the average absolute change and expressing it as a female T score (using a standard deviation for L1-L4 of 0.12g/cm² for each phantom). A regression analysis was performed to evaluate the estimation of BMD and area from theoretical measures for the GE-LASP. An ANOVA was performed to determine if the means were different between angles for each phantom. To determine if the mean BMD at each angle was different from 0º a Student’s T-test was performed.

Results

A complication in the analysis is caused by the projection of spinous processes. Normally, lateral spinous processes are not included by the analysis algorithms, and ideally should not be included. The difficulty relates to the density threshold level where a rotated spine would have the processes excluded, and at rotation angles above 20º this may become too subjective for reproducible analysis.

The potential for over-diagnosis may be significant. Figure 4 illustrates a real patient with an estimated 22º rotation of the spine, which would be a ~0.5 SD lower than the actual BMD, demonstrating that such rotations can occur physiologically.

Theoretical Correction
The amount of axial rotation may be derived using simple trigonometric principles. If we assume the vertebral body (VB) is cylindrical, then the highest density point on the projection should be the base of the posterior process. The distance of this point from the centre of the VB (\(X_p\), and the radius of the VB (R) may be used to determine the axial rotation (\(\alpha\)):

\[ \alpha = \arcsin \left( \frac{X_p}{R} \right) \]

This would require caution in use, as scoliotic spines would not have a uniform change in rotation at each vertebra.

Discussion
This study demonstrates that changes due to axial rotation may significantly alter spine BMD measurements. In the GE-LASP a sinusoidal function describes the changes rising to a peak at 90° rotation before falling. Examination of the change on T score indicates that a 16° or greater change in axial rotation may account for an apparent 0.5 SD or greater increase in BMD, even though the amount of bone is unchanged. The nature of the angle/BMD curve in this model is best explained by the simple geometry which aims to simulate a real spine only when horizontal.

We had previously postulated that the posterior processes of the spine, when projected beyond the vertebral bodies (due to axial rotation) would cause a decrease in the observed density, and the measurement of the Hologic Anthropomorphic spine phantom clearly illustrates this. The results show that rotation of 20° can decrease apparent BMD by more than 0.5 SD.

Conclusion
The simple model using the GE-Lunar Aluminium spine phantom in this study demonstrates that changes in rotation of bone from the ideal will have an effect on lumbar spine DXA results. This is limited by the flattened nature of the phantom, which is anthropomorphic in one plane only.

The Hologic Anthropomorphic spine phantom extends the model, and demonstrates that a rotation of 20° or more may affect lumbar spine DXA results. This phantom also has limitation, the most significant being its uniform density (figure 5) compared to a real spine. The complex symmetry of the phantom better demonstrates the effect of rotation in a real spine (figure 6).

In reporting DXA scans both operators and physicians should be aware of the potential for misdiagnosis as a result of such rotation.

It may be possible to partially compensate for this rotation with an anatomically correct model.

Additional studies are planned using cadaveric spines to measure the magnitude of the change in a more anatomically accurate model.

References
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