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The relationship between Computed Tomography and DXA results: A potential bias in Bone Mineral Density assessment

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RESEARCH

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ABSTRACT

Background

It has been reported that the results of the lumbar spine bone mineral density assessment can be strongly biased by degenerative changes. However, the reported data remains controversial and a potential bias has not been assessed.

Aims

To evaluate the relationships between the results of DXA and CT with the assessment of potential bias related to the influence of different structures.

Methods

This is a cross-sectional study and 25 patients were enrolled. Using DXA scan, Bone Mineral density (BMD) (g/cm^2) was calculated from 100 vertebra from the lumbar spine. Out of all the CT measurements, a mean radiodensity in HU (Hounsfield Units) for cancellous bone and total vertebra body, a mean square and radiodensity of vertebra pedicles and facet were calculated.

Results

Linear regression analysis demonstrated a strong correlation between BMD measured by DXA and CT data. Multiple correlation coefficient of model accounts for 0.8093, r2=0.6550, *p*<0.0001. Parameters that have significant relationships with the results of DXA were: a product of facet joints radiodensity and mean square on axial images (B= 0.000003379, *p*<0.0001) and total vertebral body radiodensity B=0.0016395253, p=0.0201. Beta coefficients for those variables accounted for 0.6729 and 0.3037 respectively.

Conclusion

The results of the bone mineral density assessment of the lumbar spine using DXA, can be strongly influenced by facet joints condition, especially in cases of degenerative changes. The results of BMD, provided by DXA, are partly relevant to vertebral body bone quality assessment and irrelevant to the characteristics of bone in pedicles. This means that the prognostic value of the DXA measurement results might be limited in relation to predicting low energy vertebra fracture and implant stability.

Key Words

Computed tomography, bone mineral density, dual energy X-ray absorptiometry, hounsfield units

What this study adds:

1. What is known about this subject?

The results of DXA can be influenced by degenerative changes of the lumbar spine; however, a potential bias has not been assessed yet.

2. What new information is offered in this study?

A relative contribution of different vertebra structures to the results of DXA was estimated and finally the extents of potential bias were assessed.

3. What are the implications for research, policy, or practice?

The reliability of the lumbar spine bone mineral density assessment using DXA is limited because of the strong influence of the hypertrophic changes in facet joints.

Background

Osteoporosis is a commonly encountered morbid condition in the older adult population that is associated with low energy fractures and it has been estimated that at least 40–50 per cent of women and 13–22 per cent of men will experience this pathology within their lifetime.[1-3] Degenerative diseases of the lumbar spine also have a high prevalence in this group of patients and sometimes this pathology requires stabilizing operative interventions, however, implant instability has a considerable incidence in this group. The reported rate of this complication varies from 4-20 per cent and even may reach a level of over 50 per cent in patients with osteoporosis.[4,5] The reported data highlights the necessity of valid bone quality assessment to predict and prevent those complications.

Dual energy x-ray absorptiometry (DXA) is frequently used to assess bone mineral density (BMD) which is a part of bone quality assessment.[3] Computed tomography (CT) is useful in the workup of a variety of spinal conditions. Also, CT data is capable of accurately defining bone density using Hounsfield units (HU). The HU scale represents the relative radiodensity of body tissue according to a calibrated gray-level scale and based on the values for air (−1000 HU) and water (0 HU), this scale is slightly non-linear.[6] Those diagnostic modalities, have to some extent, a similar principle based on the attenuation of the X-Ray energy and recently, it has been shown that bone mineral density can be calculated out of radiodensity measured in HU.[7-9] The role of DXA in bone mineral density assessment of the spine is still questioned because the reported specificity in predicting a fracture risk has been shown to be moderate.[10-12] A Possible explanation is that the results of DXA provide an integral BMD of the entire vertebra including both cortical and trabecular bony structures with a potential influence of facet joints, pedicles and aortic calcifications.[13-16]

Taking into account the importance of bone mineral density measurement as a part of bone quality assessment the relationship between the results of diagnostic tools should be studied to optimize diagnostic protocols and to assess limitations of a particular diagnostic tool. The objective of this study is to evaluate the relationships between the results of DXA and CT with the assessment of a potential bias related to the influence of different structures.

Method

This is a cross-sectional study; twenty-five patients were enrolled between August and December 2015. Patients were selected for the study inclusion, if they underwent a CT scan and DXA of the lumbar spine as part of the medical examination. Patients with a history of high energy trauma, low energy fractures and oncologic lesions were excluded from study participation. This study was reviewed and approved by local IRB committee, as long as all applied methods were conventional and no additional risks were found and informed written consent was received from all patients.

All patients underwent a DXA scan of the lumbar spine (GE Lunar Prodigy Advance; GE Healthcare, WI, USA) and as a result, the BMD (g/cm^2) was calculated for each vertebra of the lumbar spine (L1-L4 inclusive). The CT scans were performed from the T12-L5 levels using a single CT scanner (Aquilion 32, Toshiba Corporation). The scans utilized a slice thickness of 0.5mm, covering a scan area of 50cm. The scan parameters included: tube voltage 120kV, tube current 300mA, auto mAs range 180–400; 1.0 sec/3.0mm/0.5×32, helical-pitch 21.0. Integrated software was utilized for calculations of bone density (Vitrea Version 5.2.497.5523) incorporating a window width/window level ratio of 2000/500.

Measurements of bone radiodensity were obtained in HU from each vertebral body in the sagittal, axial and coronal planes from level L1 to L4 inclusive. Radiodensity was measured in two ways: a total vertebra body radiodensity including cortical bone and radiodensity of only cancellous bone were obtained. Measurements in the axial plane were taken at the level of the middle of the pedicles while those in the sagittal and coronal planes were taken along the geometric centre of vertebra body. Oval-shaped trabecular bone samples were selected using the maximal achievable diameters without traversing into cortical bone to calculate bone density in each plane and only cancellous bone density was measured. Once radiodensity had been measured in three planes, a mean value in HU was calculated for cancellous bone and a total vertebra body radiodensity. To study the impact of other structures on bone mineral density assessment using DXA, a mean square and radiodensity were calculated of the right and left vertebra pedicles in the frontal plane and a mean square and mean radiodensity were calculated of the right and left facet joints in the axial plain those measurements were done for each vertebra. Measurements of the facet joints parameters were performed on the level of an upper endplate of a vertebral body that was used as a standard landmark. Matching DXA and CT data for every vertebra were used for further calculations.

Statistical methods. A power analysis was performed prior to the study using data from a small pilot sample to determine the necessary sample size for patient recruitment. Correlation analysis, multiple linear regression analysis and factorial regression analysis (general regression model) were used to assess the relationships between matching CT data and the results of DXA and to choose an optimal subset of predictors.

Results

A total of 25 patients, ages 30–54 (mean 54.6+2.2) were enrolled in this study including 14 females (56 per cent) and 11 males (44 per cent). Using DXA and CT, the required measurements were taken from 100 lumbar vertebrae (data for L1-L4 vertebrae were obtained in each patient). The results of the CT examination and bone mineral density assessment using DXA are shown in Table 1. Linear regression analysis demonstrated a strong correlation between BMD measured by DXA (dependent variable) and CT data (predictors), however, variability of the DXA results were explained only by 65 per cent. The estimated multiple correlation coefficient of the estimated model accounts for 0.8093, $r^2=0.6550$, $p<0.0001$. The estimated regression and beta coefficients for CT parameters that reflect unique impact of a factor and statistical significance are presented in Table 2. According to the regression analysis results, the CT parameters estimated for facet joints, are the most contributing factors to the results of BMD assessment using DXA because of beta coefficient for facet joints parameters product, almost doubles the beta coefficient estimated for a total vertebra body radiodensity. The unique influence of parameters estimated for vertebral pedicles and radiodensity of cancellous bone of the vertebral body were not statistically significant. Finally, the results of regression analysis support a conclusion that the results of a vertebra column examination, when applying DXA, could be strongly influenced by facet joints condition, namely by hypertrophic changes in facet joints of the lumbar spine. Also, information provided by DXA could be irrelevant to bone mineral density of vertebral pedicles assessment.

To assess a relationship between a vertebra body and facet joints radiodensity, a linear correlation analysis was performed and the estimated results showed only a moderate correlation between studied parameters, $r=0.4854$, $p<0.0001$ (Pearson correlation). The result of the analysis shows the estimated parameters for facet joints are the most contributing factors to the results of vertebra BMD assessment by DXA, which to a major extent, are irrelevant to a vertebral body bone quality assessment.

Discussion

Osteoporosis is a frequently encountered morbid condition in the elderly population which has a strong relationship with low energy vertebra fractures incidence and unfavourable results of spinal instrumentations because of pedicle screws loosening.[3-5] It has been proven that the decreased resistance of bone to a mechanical load is associated with an altered microarchitecture caused by bone trabeculae loss. Consequently, bone quality assessment is considered essential in prediction and prevention of mentioned complications.[3,14,17] Bone mineral density measurement is frequently used as a part of bone quality assessment and it has been clearly defined, that this parameter has a strong correlation with mechanical properties of bone.[17-19]

For this purpose, DXA is the most frequently used diagnostic modality because of a lower dose exposure and less cost expense compared to those of CT and QCT use.[3,20] On the other hand, the DXA provides an areal estimate of the integral BMD of the entire vertebra including both cortical and trabecular bony structures.[13] Additionally, the values provided by DXA can be highly affected by bone size, spinal deformity or the presence of degenerative changes, that are irrelevant neither to vertebral body mechanical resistance properties nor to implant stability predicting.[13,15,21–23] In distinction, CT provides a true volumetric bone radiodensity independent of bone size and allows the trabecular bone to be sampled independently from the endplates and posterior elements.[13,24-26] Some studies provide evidence that CT numbers in HU can be easily transformed into BMD especially if a 120 kV tube is used, however, those conclusions remain debatable.[9,15] Taking into account the listed previously controversies concerning bone mineral density assessment, it has been decided to estimate a potential influence of various structures on the results of DXA in the current study.

It has been proven that vertebral pedicles provide at least 60 per cent resistance to pullout forces for pedicle screws, while the decrease in vertebra body load capacity is associated with bone trabeculae and mineral density loss in vertebra body.[14,20,27,28] The results of our study demonstrate that facet joints density is the most contributing factor to the results of DXA, furthermore, the revealed bias is worsening with the progression of hypertrophic degenerative changes in those structures, and as far as facet joints radiodensity and square on axial images, they strongly outweigh the significance of first order effects. Attenuation of X-ray energy by vertebra body has only moderate correlation with BMD data obtained using DXA. Pedicle radiodensity does not have a significant influence on the results of agglomerative analysis provided by DXA. The results of our study support a conclusion that BMD measurement using DXA, may have a limited predictive value concerning low energy vertebra fracture risk assessment and pedicle screws stability forecasting after spinal instrumentations. As far as the main contributing factor, the results of this examination are to a major extent, irrelevant to predicting the low energy vertebrae fracture and implant failure. Apparently, DXA is a reliable tool to assess bone mineral density and fracture risk of hip and distal radius. However, in certain cases, the obtained results of the lumbar spine should be checked out by either CT or quantitative CT, especially in cases of significant degenerative changes and deformities.

This study had certain limitations, which must be acknowledged. The number of participants in this study was relatively small and estimated equations are not suitable for calculations because of limited explanatory values. Nonetheless, the power analysis confirmed that the sample size was sufficient to support the conclusions reached.

Conclusion

The results of bone mineral density assessment of the lumbar spine using DXA, can be strongly influenced by facet joints condition, especially in cases of degenerative changes. The provided DXA results of BMD are partly relevant to vertebral body bone quality assessment and irrelevant to the characteristics of bone in pedicles, consequentially, the prognostic value of those results might be limited in relation to predicting low energy vertebra fractures and implant stability.

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PEER REVIEW

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CONFLICTS OF INTEREST

The authors declare that they have no competing interests.

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Table 1: The results of CT and DXA examination

	Mean	SD	Minimum	Maximum
Bone mineral density, g/cm^2	1.1264±0.0235	0.2361	0.7260	19.040
Cancellous bone radiodensity, HU	132.7350±3.9838	4.00369	42.80	25.54333
Facet joints radiodensity on axial images, HU	514.4347±12.8739	1.29381	295.0	814.0
Facet joints mean square on axial images, mm^2	246.3525±8.1115	8.15202	44.6	461.0
Pedicle radiodensity on frontal plane image, HU	552.7634±16.8496	16.93363	286	1452
Pedicle mean square on frontal plane image, mm^2	126.6732±4.5173	4.53987	33.0	302.0
Total vertebral body radiodensity HU	179.9776+4.3511	4.37280	8.76666	293.9

Table 2: Regression and beta coefficients of estimated regression model

	Beta coefficients	Regression coefficients	Statistical significance
Intercept	-	0.4967149686	p<0.0001
Cancellous bone radiodensity	-0.0867755310	-0.0005116753	0.4633
Product of facet joints radiodensity and mean square on axial images	0.6728948258	0.000003379	p<0.0001
Pedicle radiodensity on frontal images	0.0899285738	0.0001253732	0.2610
Pedicle mean square on frontal images	-0.129369054	-0.0006727354	0.0868
Total vertebral body radiodensity	0.3036834501	0.0016395253	0.0201