The use of computed tomography to assess bone density in comparison to bone density assessment by DXA method

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Aims and objectives

Osteoporosis is one of the most common diseases of civilization. It is estimated that about 50% of women and 20% of men will experience an osteoporotic fracture during their lives [1]. The number of patients with osteoporosis increases with the increase in average life span. Additionally, osteoporosis can be induced by other diseases and drugs [2,3].

As osteoporosis can progress undetected for a long time, early diagnosis is very important, particularly in patients with multiple risk factors. The gold standard for diagnosis is a bone density test by Dual-energy X-ray Absorptiometry (DXA). According to the accepted diagnostic criteria, preferred areas of evaluation are the lumbar spine and femoral neck [4].

Due to the rapid turnover of trabecular bones, bone density changes in DXA examinations are generally detected first in the lumbar spine [5]. However, as the bone density measured by DXA includes trabecular and cortical bones, the results may be influenced by degenerative changes in the spine (which are common in the population at risk for osteoporosis). This will typically lead to overestimation of the bone density and will decrease the sensitivity of the test [6].

Given the limitations of DXA in patients with degenerative changes and the low compliance for this test in populations at risk for osteoporosis, it may be beneficial to search for new diagnostic methods that may increase early detection of osteoporosis and help preventing osteoporotic fractures and their complications [7 - 9].

Computed Tomography (CT) scans of the chest and abdomen include the spine, in which bone mineral density may be evaluated. These scans are performed commonly for numerous indications. The numbers of CT scans performed annually have been steadily growing in the US and EU over the last ten years and a large portion of these scans is performed on populations at risk for osteoporosis [10]. Unfortunately, findings related to osteoporosis are typically under-reported by radiologists, [11] hence an automated method for detection of osteoporosis in CT scans may increase the awareness of radiologists to this problem and may improve the rates of reporting osteoporosis in patients who had a CT scan.

The aim of this study is to assess the accuracy of novel software (Radnostics) for automated segmentation of lumbar vertebral bodies and phantom-less measurement of bone mineral density in abdominal CT scans performed for other clinical indications, in comparison with DXA. The results obtained using the Radnostics software will be compared to DXA results.
Methods and materials

This prospective study was approved by the institutional review board. 19 subjects were recruited to the study. All Subjects underwent CT scans of the abdomen and pelvis without and with IV contrast (GE LightSpeed Pro 32). Contrast material used was either Omnipaque 350 or Optiray 350. Slice thickness was 2.5 mm in all scans. Indications for CT in all patients did not include suspected abnormalities of the spine. Most common indications were: abdominal pain and follow up of cancer to monitor response to therapy.

In all subjects DXA scans of the lumbar spine were performed as well (GE DPX Bravo densitometer). The interval between CT and DXA was between three days and two weeks. In all cases contrast was not present in the DXA images.

Four out of the 19 subjects were excluded from the study due to severe degenerative changes in the lumbar spine which resulted in significant discrepancies in the T-scores (>1) between adjacent vertebral bodies. These degenerative changes did not allow for correct assessment of bone density based on DXA. In all four cases, degenerative changes in the lumbar spine were confirmed by a radiologist who reviewed their CT scans. The remaining 15 subjects (7F, 8M, age range 32-78 years, mean age: 60.3, median: 61) were included in the study.

The CT scans were anonymized and the CT phase to be analyzed in each scan (pre or post contrast) was selected randomly. The scans were then sent for analysis using the Radnostics software. The Radnostics software performs fully automated segmentation of lumbar vertebral bodies, places a Volume of Interest (VOI) within the trabecular bone of each segmented vertebral body and calculates the bone mineral density in a phantom-less fashion, using the patient's own fat and muscle tissue at the vicinity of the vertebral spinous processes, as a reference for calibration. The software then calculates the average bone density for all the segmented vertebrae (mg/cc). The average bone densities were compared to the DXA T-scores (Post menopausal women and men aged 50 years or older) or Z-scores (premenopausal women and men younger than 50 years), which served as a reference standard. Based on WHO diagnostic criteria, the following values were assumed for T-score: normal bone density T-Score >= -1, osteopenia T-Score < -1 > -2.5, osteoporosis T-Score <= -2.5. Three subjects were younger than 50 years. For these three subjects Z-Score was used instead of T-Score. For Z-Score the following was assumed: normal bone density Z-Score >= -2, abnormal bone density Z-Score < -2.

For the analysis of CT scans using Radnostics, in accordance with the criteria of the American College of Radiology (ACR), bone density of 120mg/cc or higher was considered normal. All Densities below this level were considered as indicative of osteopenia or osteoporosis.
Based on DXA results, out of the 15 subjects enrolled in the study, six were diagnosed with osteoporosis (4F, 2M), six were diagnosed with osteopenia (3F, 3M), and three were considered healthy (3M).

Eight of the CT scans analyzed were in the non-contrast phase and seven were post IV contrast injection. Based on the CT analysis 13 patients (7F, 6M) had an abnormal bone density (< 120mg/cc) and two patients (2M) had a normal bone density.

All patients diagnosed with osteopenia or osteoporosis on DXA had an abnormal bone density on CT. One of the three patients in the healthy group also had an abnormal density on CT.

**Table 1. CT Analysis results compared to DXA results.**

<table>
<thead>
<tr>
<th></th>
<th>Patients with osteoporosis/osteopenia</th>
<th>Patients with normal bone density</th>
</tr>
</thead>
<tbody>
<tr>
<td>True Positive</td>
<td>False Negative (FN)</td>
<td>False Positive (FP)</td>
</tr>
<tr>
<td>(TP)</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>False Negative</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>False Positive</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>True Negative</td>
<td>2</td>
<td>4</td>
</tr>
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</table>

The sensitivity of the test is 100% and the specificity 66.7%.

The positive likelihood ratio is 3.

The negative likelihood ratio is 0.

**Table 2. results comparison per subject.**

<table>
<thead>
<tr>
<th>DXA Result</th>
<th>Subject</th>
<th>BMD [mg/cc] Contrast Phase</th>
<th>BMD [mg/cc] Non Contrast Phase</th>
<th>T-Score</th>
<th>Z-Score</th>
</tr>
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<tbody>
<tr>
<td>normal</td>
<td>1</td>
<td>-</td>
<td>198</td>
<td>-</td>
<td>0,2</td>
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<tr>
<td>normal</td>
<td>2</td>
<td>-</td>
<td>72</td>
<td>0,1</td>
<td>-</td>
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<td></td>
<td></td>
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<td>-----</td>
<td></td>
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<tr>
<td>normal</td>
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<td>-</td>
<td>151</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>osteopenia</td>
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<td>92</td>
<td>-</td>
<td>-2,1</td>
<td></td>
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<tr>
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<td>5</td>
<td>99</td>
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<td>6</td>
<td>28</td>
<td>-</td>
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<tr>
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<td>7</td>
<td>71</td>
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<td>-</td>
<td>84</td>
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<td></td>
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<tr>
<td>osteopenia</td>
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<td>-</td>
<td>64</td>
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<tr>
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<td>-</td>
<td>115</td>
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<tr>
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<td>36</td>
<td>-</td>
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<tr>
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<td>-</td>
<td>69</td>
<td>-3,4</td>
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<tr>
<td>osteoporosis</td>
<td>15</td>
<td>-</td>
<td>70</td>
<td>-2,7</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 1: White Male, age: 68. DXA result - osteoporosis. Diagnosis based on L2 - L4.

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**Fig. 2:** Radnostics results for the same subject as in figure 1. The analysis was performed on the noncontrast phase of the scan. On the left side of the image, there is a mid-sagittal reconstruction in bone window demonstrating demineralization of the lumbar vertebrae as well as mild biconcave deformities of L1-3 vertebral bodies (Marked as A, B and C on the image), consistent with grade I osteoporotic fractures. The table on the right side of the image demonstrates coronal and sagittal reformats of each segmented vertebral body (right two columns) and bone mineral density (BMD) measurements (middle two columns) for each vertebrae, as well as average BMD of all the segmented vertebrae in the bottom row (marked as Total). The C- column refers to BMD measurement assuming a noncontrast phase and the C+ columns refers to BMD values assuming the scan was performed with IV contrast. In this case as the analysis was performed on the noncontrast phase, the C- column should be used and the C+ column should be disregarded. The second column demonstrates the density values in Hounsfield Units (HU). The total BMD is 69 mg/cc (<120 mg/cc) which is consistent with low BMD according to ACR criteria.

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Conclusion

This study demonstrated that automated analysis of the lumbar vertebrae in CT scans of the abdomen produced high sensitivity when compared to DXA results, however, the specificity of the test was moderate. This may be caused by the fact that this study compared the results of density measurements in the trabecular bone of vertebral bodies, as typically done in Quantitative CT (QCT), to DXA scans' results, in which bone densities are measured in the entire vertebra including the cortex. Prior studies have shown that there is a difference between bone densities measured in DXA and those measured in QCT and in fact QCT measurements are considered more accurate as they provide a better reflection of the rapid turnover of the trabecular bone [12]. Inspection of the sagittal reconstruction of the false positive case which caused the moderate specificity, demonstrated findings of osteopenia including very low density in HU, picture frame appearance, and prominence of vertical trabeculae (see figure 4).

Limitations of the study Include the following:

This preliminary study included a small sample size.

The control group was very small (3 subjects). This may present bias to the results. (A study with a larger sample size is currently being conducted).

In summary, this preliminary study demonstrated that a novel fully automated software for measurement of bone density, using abdominal CT scans performed for other clinical indications, resulted in high diagnostic accuracy. This method may be useful for early detection of osteoporosis and prevention of fractures and their devastating consequences in patients who would be otherwise undiagnosed.
**Fig. 3**: White Male, age: 76. DXA result - normal bone density. Due to differences in T-Score > 1 Between L2 and L3, only L3,L4 were used for the analysis.

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**Fig. 4:** Radnostics results for the same subject as in figure 3. The analysis was performed on the noncontrast phase of the scan. The Total BMD (from the C- column) is 72 mg/cc, consistent with abnormally low BMD. This is the only false positive case in this study in which the CT analysis result contradicts the DXA result. In this case the midsagittal image of the CT scan (on the left) demonstrates typical findings of demineralization including a "picture frame" appearance of the vertebral bodies, prominence of vertical trabeculae and very low densities as measured in HU.

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Personal information

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