Quantitative assessment of bone marrow density by HU-measurements in MDCT: an objective tool for the detection of posttraumatic bone bruise in the sacrum

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Purpose

Background:

- Multidetector computed tomography (MDCT) imaging technique of choice for evaluation of pelvic fractures, if involvement of the posterior pelvic ring is suspected \(^1\)-\(^4\)

- Diagnostic difficulties are frequently seen in the elderly osteoporotic population with sacral insufficiency fractures \(^5\),\(^6\)

- MDCT may fail in cases in which the overlying cortical bone is intact or in cases with subtle degree of trabecular disruption \(^7\),\(^8\)

- Studies demonstrated superiority of magnetic resonance imaging (MRI) in the detection of sacral insufficiency fractures \(^7\)-\(^9\)

- MRI → highly sensitive in depicting bone marrow edema and haemorrhage as well as subtle fracture lines (termed as bone bruise), which are occult in CT \(^10\)-\(^11\)

Aim:

Evaluation of bone marrow with subjective visual assessment and objective comparative ROI-based HU measurements with MRI serving as the standard of reference to detect occult sacral fractures previously not detected by CT

Hypothesis: *posttraumatic bone marrow lesions lead to increased CT attenuation levels, which may be detected by comparison of the affected with the contralateral non-affected sacral bone.*
Methods and Materials

Study Population:

- 22 consecutive pts (17w, 5m; mean age 77.4 y; range 55-96 y)
- All pts → admitted to the emergency department with posttraumatic lower back pain
- in MDCT all pts presented diagnosis of an anterior pelvic ring fracture but negative findings in the posterior pelvic ring
- all pts underwent further pelvic MRI within 7 days to rule out occult insufficiency fractures of the sacrum

MDCT and MR Imaging protocols:

<table>
<thead>
<tr>
<th>Scanparameter</th>
<th>1.5 Tesla MRI (Philips Achieva, Philips Healthcare, Best, NL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modell</td>
<td>Brilliance 64, iCT 256, iX 880 (Siemens, Erlangen, DE)</td>
</tr>
<tr>
<td>Kilovoltage</td>
<td>120 kV, 120 kV</td>
</tr>
<tr>
<td>Repetition time (msec.)</td>
<td>3609, 570, 735, 6372</td>
</tr>
<tr>
<td>Repetition time (msec.)</td>
<td>33.8, 18, 15, 80</td>
</tr>
<tr>
<td>Echo time (msec.)</td>
<td>150, –, –, –</td>
</tr>
<tr>
<td>Slice thickness (mm)</td>
<td>4, 4, 4, 4</td>
</tr>
<tr>
<td>Matrix (mm)</td>
<td>512 x 512, 512 x 512, 256 x 192, 256 x 192, 256 x 192</td>
</tr>
<tr>
<td>FOV (cm)</td>
<td>32 – 34, 32 – 34, 16 – 24, 16 – 24, 16 – 24</td>
</tr>
</tbody>
</table>

Table 2

References: medicine, diagnostic center, radiology - Hamburg/DE

Image analysis:

- two radiologists independently analyzed MDCT data sets in a randomized and blinded fashion
the sacrum of each of the 22 patients was divided into three vertical levels (1 = height of the first sacral vertebra, 2 = height of the second and 3 = height of the third sacral vertebra), resulting in an overall of 66 defined levels. At each of the 66 levels, left and right sacral portions were defined as independent anatomical regions, resulting in an overall of 132 defined regions.

Subjective image analysis:

each region was visually evaluated for the presence of abnormal soft-tissue attenuation in the soft tissue window setting by using the coronal images and a semiquantitative four-point scale:

1 = distinct signs of abnormal soft tissue-like attenuation
2 = less pronounced attenuation changes
3 = equivocal
4 = none

Objective image analysis:

both observers independently obtained HU measurements on each of the 132 defined sacral anatomical regions by placing a circular region of interest (ROI) (12-15 mm diameter) on coronal images

- observers were instructed to place the ROI in the center of the lateral sacral mass on each height, keeping a minimal distance of 4 mm from adjacent cortical bone
- For each of the 132 defined anatomical regions two HU-measurements were performed on two adjacent image slices and means of both slices were calculated
- HU attenuation differences of the 132 anatomical regions were calculated between the right and left side of each of the defined 66 anatomical levels

Reference standard analysis:

After an interval of 8 weeks readers reviewed the MRI examinations in consensus and evaluated each of the 132 defined anatomical sacral regions for the presence or absence of marrow edema and fracture lines.
Statistical Analysis:

- Scores of the visual assessment were subjected to a ROC curve analysis areas under the curve (AUC) were assessed for both readers. A cut-off between 2 and 3 was used for the four-point scale to compute sensitivity, specificity, positive predictive value, negative predictive value and accuracy.

- Interobserver agreement for visual semiquantitative image grades was assessed by weighted k statistics, with linear weightings for rating differences.

- Bland-Altman analysis (BAA) was used to demonstrate the bias and limits of agreement of quantitative HU measurements of both readers.

- Absolute attenuation values of affected and unaffected bone marrow regions as well as the differences of CT numbers of the affected and unaffected regions were compared by using the Student t test. P values < 0.05 were considered as statistically significant.

- Mean of HU measurements of both readers were calculated mean attenuation differences of each defined sacral level from CT data were subjected to ROC curve analysis, with high attenuation value differences indicating high likelihood of bone marrow edema and haemorrhage cut-off derived from ROC curves at the point of highest accuracy was used to calculate the mean sensitivity, specificity, positive predictive value, negative predictive value and accuracy.
Results

- MRI revealed bone marrow edema and trabecular fracture lines in 19 of the 132 defined regions (14.4%) in 12 of the 22 patients (54.5%) (example in figure 1).

- Visual evaluation of CT scans revealed moderate agreement between the two observers with weighted k statistics of 0.48. In ROC curve analysis combined AUC of both readers was 0.744, resulting in a sensitivity of 60.5%, a specificity of 88.3%, a positive predictive value of 68.1%, a negative predictive value of 84.7% and an accuracy of 80.3% (table 1).

- Bland-Altman analysis → good interobserver agreement (mean bias of 1.4 HU; 95% limits of agreement, ± 18.2 HU) (figure 2).

- Quantitative HU-measurements: HU values in affected regions were significantly higher than in non-affected region of the sacrum (10.2 HU ± 36.2 versus -21.9 ± 46.0 HU, p=0.0002). But, there was a great variance of absolute HU values with a large overlap of CT numbers between affected and unaffected regions (Figure 3a).

- Comparison of calculated differences of HU measurements in the affected and non-affected 66 defined levels → significant difference (52.9 HU ± 28.2 versus 10.2 ± 8.7; P<0.0001) but → markedly smaller overlap (figure 3b).

- ROC curve analysis of calculated differences of the 66 levels → high AUC = 0.886 (95% confidence interval, 0.783 - 0.951), exhibiting an ideal cut-off value of 35.7 HU density difference for differentiation between the presence and absence of bone marrow lesions (figure 4).

- Using the derived cut-off level we found a diagnostic accuracy superior to the visual evaluation (table 1).
Fig. 1: CT (A, B) and MRI (C, D) of a 81-year-old male patient with fracture of the left lateral sacral mass. Coronal CT in bone (a) and soft-tissue (b) window setting with corresponding fat-saturated T2-weighted (c) and T1-weighted MR images of a bone marrow edema and haemorrhage (hyperintense area in C) adjacent to a trabecular fracture line (arrows in d) in the left Massa lateralis at the height of the second sacral vertebra. By visual evaluation a subtle bone bruise was rated by only one observer, whereas the calculated difference (52 HU) in mean CT numbers of the left affected region (-27.2 HU) compared with that of the right non-affected region (-79.2 HU) indicated bone bruise on the left side.

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Table 1: Comparison of diagnostic performance by visual and quantitative evaluation

<table>
<thead>
<tr>
<th>Pelvic MRI</th>
<th>Visual evaluation</th>
<th>Quantitative assessment by HU-Measurements (Cut-off level: 35.7 HU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity (%)</td>
<td>60.5</td>
<td>78.9</td>
</tr>
<tr>
<td>Specificity (%)</td>
<td>88.3</td>
<td>100</td>
</tr>
<tr>
<td>PPV (%)</td>
<td>68.1</td>
<td>100</td>
</tr>
<tr>
<td>NPV (%)</td>
<td>84.7</td>
<td>92.2</td>
</tr>
<tr>
<td>Accuracy (%)</td>
<td>80.3</td>
<td>93.9</td>
</tr>
</tbody>
</table>

Table 1

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Fig. 2: Interobserver agreement. Bland-Altman plot showing differences between measurements obtained by observer 1 and observer 2. X-axis represents the average of bone marrow HU density of both observers in HU. Y-axis represents the HU bone marrow density difference between the measurements of observer 1 and observer 2. On each graph, middle solid line indicates mean bias, dotted lines above and below indicate 95% confidence intervals. Note the mean bias of 1.4 HU.
Fig. 3: Box plot analyses. (a) Box plots of absolute HU values of affected (n=19) and non-affected (N=113) sacral regions. (b) CT number differences of the left and right region at each level was calculated, and values of calculated HU differences of affected (n= 19) and non-affected (n=47) levels, as confirmed by MRI, were plotted as box plots. Both analyses show a significant difference between HU values (p=0.0002 and p
**Fig. 4:** ROC and Dot Plot analyses. (a) Receiver operating characteristic (ROC) analysis derived from calculated differences of affected and non-affected levels of the sacrum (AUC = 0.886; 95% confidence interval, 0.783 - 0.951). (b) Aligned dot plot analysis of HU values of affected and non-affected levels exhibiting an ideal cut-off value of 35.7 HU density difference for differentiation between the presence or absence of bone bruise.

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Conclusion

- differences in bone marrow density can be reliably assessed as an objective tool for detection of posttraumatic bone marrow lesions in the sacrum

- quantitative HU-measurements are feasible as a valid and reliable tool for detection of bone marrow edema and haemorrhage associated with occult fractures of the sacrum

- using a cut-off value of 35.7 HU in quantitative analysis a higher diagnostic accuracy could be achieved than by visual evaluation, achieving a diagnostic accuracy of 93.9%

- Based on the high specificity and negative predictive value, the presented technique could serve as a valuable tool to rule out occult sacral insufficiency fractures, avoiding further diagnostic workup with MRI and aiding more accurate treatment decisions
References


