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FULL PAPER

The feasibility of dual-energy CT in differentiation of vertebral compression fractures

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Objective: To prospectively evaluate the ability of dual-energy CT (DECT), compared with MRI, to identify vertebral compression fractures in acute trauma patients.

Methods: This institutional review board-approved study included 23 consecutive patients with 32 vertebral fractures who underwent both DECT and MRI of the spine between February 2014 and September 2014. A total of 209 vertebrae were evaluated for the presence of abnormal bone marrow attenuation on DECT and signal on MRI by five experienced radiologists. The specificity, sensitivity, predictive values and intraobserver and interobserver agreements were calculated.

Results: MRI revealed a total of 47 vertebrae (22.4% of all vertebrae) and DECT revealed 44 vertebrae (21.0% of all vertebrae) with oedema. Using MRI as the reference standard, DECT had sensitivity, specificity, positive-predictive

value, negative-predictive value and accuracy of 89.3, 98.7, 95.4, 96.9 and 96.6%, respectively. With respect to establishing the presence of oedema, the inter-observer agreement was almost perfect ($k = 0.82$), and the intraobserver agreement was substantial ($k = 0.80$).

Conclusion: Compared with MRI, DECT can provide an accurate demonstration of acute vertebral fractures and can be used as an alternative imaging modality for the assessment of vertebral fractures in patients with contraindications for MRI.

Advances in knowledge: Distinguishing of acute and chronic vertebral compression fracture is important for treatment choices. DECT is very fast compared with MRI and is an alternative imaging modality for the assessment of vertebral fractures in patients with contraindications for MRI.

INTRODUCTION

Vertebral compression fractures are a common clinical problem, especially in the elderly population, and are associated with a decreased quality of life and increased mortality.^{1,2} Imaging procedures are important for determining the location of the fracture, selecting the optimal treatment and preventing associated complications. In addition to radiography, MRI, bone scintigraphy and CT can be used to evaluate vertebral fractures.^{3,4} Among these procedures, MRI is the modality of choice to obtain information about both vertebral fractures and bone marrow oedema.^{5–8} However, MRI is not routinely used in all patients with vertebral trauma owing to reduced availability, contraindications and/or metal artefacts. Compared with MRI, CT is more available, requires less time and has better spatial resolution.^{9,10} Although bones can be removed on single-energy CT images, the surrounding trabecular structures complicate the visualization of vertebral oedema.^{5,11–14} With

the advancements in dual-energy CT technology, material decomposition and the elimination of misregistration artefacts are possible.¹⁵ Materials, particularly those with high atomic weight numbers (e.g. iodine and calcium), display different attenuation measurements at different kilovoltage peak levels.¹⁶ The determination of the presence of bone marrow oedema using dual-source CT (DSCT) is beneficial for rapidly initiating appropriate treatment.

Thus, the purpose of our study was to investigate the reproducibility of DSCT in the evaluation of vertebral fractures and bone marrow oedema with a 256-slice DSCT system and to determine the differences between DSCT and MRI.

METHODS AND MATERIALS

Patients

Between February 2014 and September 2014, 26 consecutive patients who underwent both DSCT and MRI with the

diagnosis of acute vertebral compression fracture by radiography were included in the study. The study was approved by the institutional review board, and all patients provided informed consent. The mean time interval between the trauma and first imaging was 6 h (range, 1–14 h). The mean time interval between the DSCT and MRI was 3 days (range, 0–14 days), and there were no complications from either DSCT or MRI. The exclusion criteria were as follows: pregnancy, age less than 18 years, contraindications for MRI (e.g. non-MRI-compatible pacemaker), metal implants and diseases associated with abnormal bone marrow attenuation (e.g. neoplastic diseases). One patient with inadequate MR image quality due to metal implants and two patients with tumoral fractures, proven in the follow-up, were excluded. A total of 23 patients (5 males and 18 females) with a mean age of 61 ± 15 years (range, 35–77 years) were finally included in our study; therefore, 209 vertebral bodies were evaluated. No conflicts of interest are reported for all authors. The authors had full control of all data and information presented in this article.

Dual-source CT protocol

The DSCT examinations were performed with a 256-slice DSCT (Somatom® Definition Flash, Siemens Healthcare, Forchheim, Germany). The scanner was equipped with two X-ray tubes (low and high kilovoltage) and two corresponding detectors orientated in the gantry with an angular offset of 95° .¹⁷ The scanning protocols conducted using the dual-energy protocol in the cranio-caudal scan direction were as follows: tube voltages set at 140 kV (Tube A, 250 mA) and 80 kV (Tube B, 500 mA); gantry rotation time, 0.5 s; collimation, 128×0.625 mm; and pitch, 0.7. The mean volume CT dose index of this protocol was $15.6 \text{ mGy} \pm 3.2$ (range, 6.1–21.8 mGy). No intravenous contrast agent was administered. After each DSCT, three data sets were acquired: an 80-kVp set, a 140-kVp set with a tin filter and an average-weighted set. The average-weighted set was calculated from both tube data at a ratio of 0.6:0.4 to imitate the characteristics of a single 120-kVp image. Axial images were reconstructed for all three data sets with a slice thickness of 1 mm and 0.4-mm increments using a bone kernel (B70f) and a soft-tissue kernel (D30f). All image data sets were transferred to an offline workstation (Syngo® dual energy Workplace version VE36A; Siemens, Erlangen, Germany) for the analysis of reconstructed multiplanar reformatted images in the coronal and sagittal views. Image analysis was based on a three-material decomposition algorithm for the bone mineral, yellow marrow and red marrow.^{18–21} For our evaluation of the vertebral bodies, the relative contrast material ratio was set to a value of 1.75, and the range of the filter was set to 3 based on the experience from previous studies.^{5,11,22,23} Non-calcium images were displayed in greyscale.

MRI protocol

All patients underwent MRI with a 3.0-T system (MAGNETOM® Skyra, Siemens Healthcare, Germany) and with a spine surface coil in the supine position. The MRI sequence protocols using the trauma protocol were as follows: sagittal spin-echo T_1 weighted images [repetition time (TR) = 490–577 ms, echo time (TE) = 10–11 ms, slice thickness = 3.5–4 mm, matrix = 512×497 – 512×512 , bandwidth = 146–190 Hz, number of excitations = 2 and echo train = 2–3], sagittal short tau

inversion-recovery (STIR) images (TR = 4700–6000 ms; TE = 81–84 ms, inversion time = 160 ms, slice thickness = 3.5–4 mm, matrix = 384×320 – 448×377 , bandwidth = 175–177 Hz, number of excitations = 1 and echo train = 16–19) and axial STIR images (TR = 4700–6000 ms, TE = 81–84 ms, inversion time = 160 ms, slice thickness = 3.5–4 mm, matrix = 384×320 – 448×377 , bandwidth = 175–177 Hz, number of excitations = 1 and echo train = 16–19).

Image analysis

Two independent radiologists (MK and LK with 20 and 15 years' experience in radiology, respectively) analysed all DSCT images on the sagittal plane in a random order, after training on four additional patients who were not included in this study. The readers were free to modify the window-level settings of the images and were blinded to each other and to the MRI findings. Each vertebral body available for analysis on the imaging examinations was evaluated for the presence of traumatic bone marrow lesions using a binary classification system (1 = indicates abnormal bone marrow attenuation and 0 = normal bone marrow). For any disagreement on vertebral fractures or oedema, a consensus reading was appended, and the consensual results were used for further analysis. For the quantitative image analysis, circular regions of interest with a mean area of 0.5 cm^2 were located at the vertebral body, 2 mm away from the adjacent cortical bone (Figure 1). Two regions of interest were achieved on greyscale images, and the mean value was calculated. The height diameter reduction in the anterior, middle or posterior part of the vertebral corpus from the sagittal images was defined and classified according to the Genant vertebral fracture grading system. The absence of vertebral height diameter reduction was defined as grade 0, 20–25% height diameter reduction as grade 1, 25–40% height diameter reduction as grade 2 and >40% height diameter reduction as grade 3. To determine the intraobserver agreement, the DSCT images were re-evaluated after 15 days.

The MR examinations were analysed in a random order as the standard of reference for the presence or absence of bone marrow oedema by two other radiologists (HO and ZY with 10 and 7 years' experience in radiology, respectively). The readers were blinded to the DSCT findings. In instances of disagreement, a third reader (MK, with 20 years' experience in radiology) was asked to adjudicate. All vertebral bodies available on sagittal spin-echo T_1 weighted and STIR images were evaluated for the presence of traumatic bone marrow lesions using a binary classification system (1 = indicates abnormal bone marrow attenuation and 0 = normal bone marrow). Bone marrow oedema was defined as low signal areas on T_1 weighted images and as high signal areas on STIR images.^{1,24,25}

Statistical analysis

Continuous variables are expressed as the mean $\pm$ standard deviation or as the median with interquartile range when not normally distributed; categorical variables are presented as counts and/or percentages. The statistical analyses were performed with SPSS® 17.0 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL). Continuous variables were compared using t test, and categorical variables were analysed using χ^2 test. The sensitivity, specificity, positive-predictive value (PPV),

Figure 1. Images from a 30-year-old male with a compression fracture at T₁. (a) Sagittal and (b) axial dual-energy CT bone window images show the number of region of interest (ROI).

negative-predictive value (NPV) and accuracy of DSCT for the detection of oedema were evaluated using MRI as the reference standard on a per-vertebra basis. Interobserver agreement for the qualitative analysis was calculated with weighted κ statistics. The degree of agreement based on kappa values was as follows: 0, none; 0–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; and 0.81–1.00, almost perfect. A p -value < 0.001 was considered indicative of a statistically significant difference.

RESULTS

DSCT and MRI were successfully performed in all patients (5 males and 18 females patients). In the 23 patients, a total of 209 vertebrae (124 thoracic and 85 lumbar) were included for evaluation, and none of the vertebrae had to be excluded owing to non-diagnostic image quality. A total of 72 vertebrae were located from levels T1 to T12 in 6 patients, 14 vertebrae were located from levels T4 to L5 in 1 patient, 45 vertebrae were located from levels T9 to L5 in 5 patients, 40 vertebrae were located from levels T10 to L5 in 5 patients, 14 vertebrae were located from levels T11 to L5 in 2 patients and 24 vertebrae were located from levels T12 to L5 in 4 patients. According to the Genant grading system for vertebral fractures, 64 vertebral bodies were classified as grade 0, 83 vertebral bodies as grade 1, 40 vertebral bodies as grade 2 and 22 vertebral bodies as grade 3 (Table 1). MRI revealed a total of 47 vertebrae (22.4% of all vertebrae) with oedema in 21 patients and 162 vertebrae (77.5%) with a normal signal pattern in 23 patients. DSCT revealed 44 vertebrae (21.0% of

all vertebrae) with oedema in 22 patients and 165 vertebrae (78.9%) with normal attenuation in 23 patients (Figure 2a–c).

The attenuation values of the vertebral bodies with oedema on MRI and on DSCT with non-calcium images were significantly high compared with normal vertebral bodies on MRI ($p < 0.001$).

A correlation analysis was performed after dividing the entire population into age, vertebral level and gender subgroups. There was a significant correlation with respect to age and vertebral levels but not with gender ($p < 0.001$).

The comparison of MRI and DSCT oedema according to the thoracic and lumbar levels is shown in Table 2.

Two of five false-negative findings were determined at the thoracic level, and three false-negative findings at the lumbar level. Additionally, the thoracic and lumbar levels each produced one false-positive finding.

With respect to the establishment of oedema, the interobserver agreement was almost perfect ($k = 0.82$), and the intraobserver agreement was substantial ($k = 0.80$).

Using MRI as the reference standard, DSCT had sensitivity, specificity, PPV, NPV and accuracy of 89.3, 98.7, 95.4, 96.9 and 96.6%, respectively, for detecting vertebral oedema. In the group with

Table 1. Comparison of the Genant grading system with vertebral body oedema detected with both DSCT and MRI

Grade	Vertebra body	MRI oedema	No MRI oedema	DSCT oedema	No DSCT oedema
Grade 0	64	2	62	2	62
Grade 1	83	4	79	2	81
Grade 2	40	21	19	20	20
Grade 3	22	20	2	20	2
Total	209	47	162	44	165

DSCT, dual-source CT.

Figure 2. Images from a 30-year-old male with compression fractures at T1 and T5. (a) Sagittal short tau inversion-recovery turbo spin-echo MR image, (b) dual-energy CT scan with bone window and (c) colour map settings.

vertebral height diameter reduction $>20\%$, DSCT had sensitivity, specificity, PPV, NPV and accuracy of 91.1, 99, 97.6, 96.1, and 96.5%, respectively, for detecting vertebral oedema (Figure 3a, b).

DISCUSSION

Vertebral fractures are often barely noticeable compared with appendicular bone fractures.²⁶ Bone morphology and bone marrow abnormalities have been evaluated for the prediction of vertebral fractures.^{27,28} Bone marrow abnormalities can be caused by increases or decreases in the component composition of fat and fluid. Removing the calcium from images with DSCT enables the analysis of the bone marrow for abnormalities.

In this article, we confirmed that DSCT findings with non-calcium images are helpful for detecting the presence of bone marrow oedema and in discriminating between acute and chronic compression fractures of the spine. Currently, only a few studies have reported on the use of DSCT to visualize the bone marrow.^{1,5,11,23,29}

The attenuation values measured on the non-calcium images obtained by DSCT were higher in abnormal bone marrow areas than in normal areas. These increased attenuation values are correlated with the knowledge about the increase in fluid and/or blood components of the bone marrow in trauma patients.^{5,30,31} However, the attenuation difference between abnormal and normal bone marrow is greater in elderly patients owing to the increased fat component of their vertebrae.⁵

The three false-negative findings were in the vertebral bodies with sclerosis. Chronic or healed fractures will not cause

oedema signal changes on MRI as a result of sclerosis or bone regeneration.³² Moreover, sclerosis causes reduced attenuation of the vertebral body on non-calcium images obtained by DSCT.⁵ Two fractures close to the vertebral endplates were the reason for the other false-negative findings. In a similar study, Wang et al reported the superiority of MRI for fractures near endplates, which was supported by the data from our study. The two false-positive findings occurred in young patients and were evaluated as red bone marrow areas in the vertebral bodies, as noted in a previous study.¹

The results are compatible with previous studies related to the assessment of bone marrow in spine trauma.^{1,5} The sensitivity, specificity and predictive values for the assessment of vertebral oedema obtained in our study were similar to the values obtained in the studies of Wang et al and Bierry et al. The assessment of both DSCT images and non-calcium images for oedema, knowledge regarding fracture classification and sclerotic changes may affect these sensitivity values.

The limitations of our study should be recognized. The patient population was relatively small. Our results need to be confirmed in a larger prospective study in terms of both the number and distribution of the patients. Although most of the patients in this study were elderly, we did not include the osteoporosis data of the patients. We also did not include any pathologic fractures in this study. Thus, the results cannot be generalized. The second limitation is that although four patients were reviewed for the evaluation of bone marrow

Table 2. Comparison of MRI and DSCT oedema on a level basis

	Thoracic levels			Lumbar levels		
	DSCT oedema	No DSCT oedema	Total	DSCT oedema	No DSCT oedema	Total
MRI oedema	21	2	23	21	3	24
No MRI oedema	1	100	101	1	60	61
Total	22	102	124	22	63	85

DSCT, dual-source CT.

Figure 3. Images from a 27-year-old female with chronic compression fractures at L3. (a) Dual-energy CT scan with bone window and (b) sagittal short tau inversion-recovery turbo spin-echo MR image.

changes on the DSCT images, operator experience may have had a significant influence on the test results. The failure to evaluate the relationship between the surgical reference of the patients and DSCT results is another limitation of this study.

To improve the detection and characterization of bone marrow oedema in vertebral fractures, using iterative reconstruction techniques, minimizing artefacts from metal prostheses and

visualizing normal and abnormal ligaments and tendons need to be further investigated.

In conclusion, compared with MRI, DSCT with reconstructed non-calcium images has high specificity and diagnostic accuracy for the evaluation of bone marrow oedema in vertebral fractures. DSCT scanning can be used routinely in the clinic as an alternative imaging modality for the assessment of vertebral fractures in patients with contraindications for MRI.

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