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# Dual-energy CT virtual non-calcium technique for detection of bone marrow edema in patients with vertebral fractures: A prospective feasibility study on a single- source volume CT scanner

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ABSTRACT

*Objectives:* Dual-energy computed tomography (DECT) is a recent development for detecting bone marrow edema (BME) in patients with vertebral compression fractures. The aim of this pilot study was to determine the reliability of single-source DECT in detecting vertebral BME using magnetic resonance imaging (MRI) as standard of reference.

*Materials and methods:* Nine patients with radiographic thoracic or lumbar vertebral compression fractures underwent both, DECT on a 320-row single-source scanner and 1.5 T MRI. Virtual non-calcium (VNC) images were reconstructed from the DECT volume datasets. Three blinded readers independently scored images for the presence of BME. Only vertebrae with loss of height in radiography (target vertebrae) were included in the analysis. A vertebra was counted as positive if two readers agreed on the presence of BME. Cohen's kappa was calculated for interrater comparison. Intervertebral ratios of target and the reference vertebra were compared for CT attenuation and MR signal intensity in a reference vertebra using Spearman correlation. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated.

*Results:* Fourteen target vertebrae with a radiographic height loss were identified; eight of them showed BME on MRI, while DECT identified BME in 7 instances. There were no false positive virtual non-calcium images, resulting in a sensitivity of 0.88 (0.75–1.0 among all readers) and specificity of 1.0 (0.81–1.0). Interrater agreement was inferior for DECT ($\kappa = 0.63–0.89$) compared to MRI ($\kappa = 0.9–1.0$). Intervertebral ratio in VNC images strongly correlated with short-tau inversion recovery ($r = 0.87$) and inversely with T1 (-0.89). SNR (0.2 +/− 0.2 in VNC and 16.7 +/− 7.3 in STIR) and CNR (0.2 +/− 0.3 and 7.1 +/− 6.3) values were inferior in VNC.

*Conclusions:* Detecting BME with single-source DECT is feasible and allows detection of vertebral compression fractures with reasonably high sensitivity and specificity. However, image quality of VNC reconstructions has to be improved to achieve better interrater agreement. Nonetheless, DECT might accelerate the diagnostic work-flow in patients with vertebral compression fractures in the future and reduce the number of additional MRI examinations.



## 1. Introduction

Dual-energy computed tomography (DECT) is an emerging imaging technique with an increasing role in the diagnosis of musculoskeletal diseases, allowing detection of tophi in gouty arthritis [1] and bone marrow edema (BME) after trauma using the virtual non-calcium (VNC) technique [2–4]. The latter has the potential to improve the diagnostic process in patients with osteoporotic fractures by detecting BME, which is present in acute fractures but uncommon after consolidation [5].

In the elderly, osteoporotic vertebral fractures are frequent with an annual incidence of 1.1% in women and 0.6% in men [6], thus having a considerable socioeconomic impact. Imaging is an essential component of the diagnostic pathway including bone density measurements, computed tomography (CT) – the gold standard for assessing structure and stability – and magnetic resonance imaging (MRI) for estimating fracture age [4,7,8]. Unstable fractures,

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even if less common with osteoporotic disease, require immediate surgery; however, only fractures presenting with BME may benefit from kyphoplasty [9]. When patients are examined by DECT instead of conventional CT, information about BME and, therefore, the age of the fracture might be derived simultaneously and faster.

Earlier studies of the role of DECT in spinal fractures were done on dedicated dual-source CT scanners, which are equipped with two separate x-ray tubes and simultaneously acquire two datasets with different energy levels [4,5,10,11]. However, different approaches have been proposed to also perform DECT examinations on conventional (single-source) CT scanners. Basically, DECT can be performed either by acquiring two completely separate spiral CT scans with different tube current settings and using co-registration with special software or, if a detector with enough z-axis coverage is available, by acquiring two volume scans directly one after the other without table movement [12,13]. The option of performing DECT examinations on conventional single-source CT scanners is of high clinical relevance since dual-source systems are not available in every hospital.

To reduce the costs of imaging and to offer patients the optimal treatment more quickly, the possibilities of single-source DECT (S-DECT) should be investigated further. The aim of this pilot study was to assess the validity of VNC imaging using S-DECT and to compare its ability to detect BME with MRI as standard of reference.

## 2. Material and methods

### 2.1. Subjects

In this prospective pilot study, we included a total of nine consecutive patients who were admitted to our emergency room between November 2014 and August 2015 and examined on the same CT machine. All patients presented with severe back pain and had a spontaneous vertebral compression fracture on radiography. Their symptoms and clinical findings required further imaging workup with CT and MRI. Patients who had contraindications to MRI or did not complete the examination were not included.

The local ethics review board approved the study (EA1/372/14). All patients gave written informed consent. Additional approval by the Federal Office for Radiation Protection was waived by the ethics committee.

### 2.2. Target and reference vertebrae

Radiographs were evaluated in a separate consensus reading. Based on radiography vertebrae with a loss of height were defined as target vertebrae. Target vertebrae with BME in MRI seen by two of three readers were counted positive for BME, other vertebrae were classified as negative. Additionally, a reference vertebra was defined for each patient before scoring. The reference vertebra had to meet different criteria: (i) It is the lowest vertebra that is depicted in both S-DECT and MRI. (ii) It has normal appearance without loss of height in all imaging techniques. (iii) It was not subject to previous interventional treatment (e.g., spinal fusion or kyphoplasty). Target and reference vertebrae were defined before pseudonymization and image reading.

### 2.3. Imaging procedures

S-DECT imaging was performed on a 320-row CT scanner (Toshiba AQUILION One Vision; Toshiba Medical Systems; Otawara, Japan; installed in 2013). Two volumes with 135 kV and 80 kV were acquired separately using the wide-volume mode and automatic dose adjustment with an SD of 12. Images were calculated using iterative reconstruction (AIDR 3D standard) and a medium soft tissue kernel without beam hardening compensation for VNC reconstruction and a sharp bone kernel for reconstruction of morphologic images. For identification of BME, VNC volume reconstructions with 0.5 mm contiguous slice thickness was generated from the dual-energy datasets using the software on the CT console (Dual Energy Image View, Version 6; Toshiba Medical Systems; Otawara, Japan). The dual-energy gradient was changed from 0.55 for iodine to 0.69 for calcium to create virtual non-calcium instead of virtual non-contrast images. Object formula were 0/0 for water and −136/-106 (80 kV/135 kV) for fat. For image reading, the VNC volume was reformatted to generate 5 mm multiplanar reconstructions. The computed tomography dose index (CTDI) and dose-length product (DLP) were recorded, and the estimated effective dose was calculated from the DLP using a conversion coefficient of 0.01.

MRI was performed at 1.5 T (MAGNETOM Avanto; Siemens; Erlangen, Germany; installed in 2009 or MAGNETOM Symphony Vision; Siemens; Erlangen, Germany; installed in 1996 and upgraded in 2001). T1-, T2- and short tau inversion recovery (STIR)-weighted sequences were acquired (see Table 1 for details).

**Table 1**
MRI acquisition parameters.

| Sequence | TR | TE | TI | Thickness [mm] |
|---|---|---|---|---|
| **T1** | 551 | 12 | – | 3.0 |
| **T2** | 7040 | 142 | – | 3.0 |
| **STIR** | 6150 | 31 | 150 | 3.0 |

TR: repetition time, TE: echo time, TI: inversion time, Thickness: slice thickness measured in mm (3.3 mm spacing between slices).

### 2.4. Image reading

Three readers blinded to identifying information, clinical data, images and results of the other modalities independently evaluated the images in two sessions (one for S-DECT and one for MRI) at least six months after all images had been acquired, unaware as to which vertebrae were defined as target or reference vertebrae. The readers had different experience in musculoskeletal image interpretation (reader 1: a traumatic surgeon with 3 years experience, reader 2: a radiologist with 6 years experience, reader 3: a senior radiologist with 15 years experience). Images were scored for the presence of BME assigning grades of 0–3 (0: no edema, 1: small or localized edema, 2: considerable edema affecting most of the vertebral body, 3: severe edema affecting the whole vertebral body). Furthermore, for vertebral bodies scored as edema positive, readers rated their diagnostic confidence on a scale of 0–10 (0: not at all confident, 10: no doubt). Finally, readers were asked to subjectively evaluate image quality of VNC reconstructions and MRI-STIR sequence on a 0–10 scale (0: poor image quality/nondiagnostic, 10: excellent image quality). Readers had access to all images of the modality during scoring (e.g., when scoring VNC images also to the CT images reconstructed in bone kernel to look for sclerosis that might imitate BME). However, subject to scoring were only VNC reconstructions and STIR images.

### 2.5. Objective image parameters

Reader 2 performed region-of-interest (ROI) measurements in sagittal slice orientation for conventional CT with 135 kV, VNC, T1-weighted and STIR images in the center of the vertebral body, where the central vein can be found. A polygonal ROI was used covering as much of the bone marrow as possible with a distance of at least 2 mm from cortical bone. Mean attenuation values (CT and VNC) and mean signal intensity values (T1 and STIR), together with standard deviations, were collected for target and reference vertebrae and for surrounding air outside the patient.