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Research article

Bone marrow edema in traumatic vertebral compression fractures: Diagnostic accuracy of dual-layer detector CT using calcium suppressed images

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ABSTRACT

Purpose: To evaluate calcium suppressed images (CaSupp) in dual-layer detector computed tomography (DLCT) for the detection of bone marrow edema (BME) in vertebral fractures.

Materials and methods: The retrospective study was approved by the institutional review board. 34 patients with synchronous DLCT and MRI, who were diagnosed with one or more acute vertebral fractures, were included. MRI were systematically analyzed as reference standard. Two blinded and independent readers evaluated CaSupp for vertebral BME. Additionally, both readers determined the optimal calcium suppression indices (CaSupp-I) for visualization of BME in consensus and correlated the CaSupp-I with parallel measurement of trabecular density as surrogate parameter for bone mineral density. ROI-based measurements of the contrast-to-noise ratios (CNR) were also conducted. Interrater agreement was determined by kappa-statistics. CNR were analyzed using Wilcoxon signed rank test.

Results: Fifty-seven acute fractured vertebrae out of 383 vertebrae (14.9%) were found. CaSupp yielded an average sensitivity of 87% and specificity of 99%, a positive predictive value of 95%, a negative predictive value of 98% and an accuracy of 97% for the detection of fracture-associated edema. Interrater agreement was excellent (kappa 0.91). Increase in CNR of BME correlated with increasing CaSupp-I. Edema adjacent to the cortical endplates was better visualized using CaSupp-I of 70 and 80, while extensive edema was better visualized using a CaSupp-I of 90 and 100 (chi2 < 0.0001). No correlation between optimal CaSupp-I and trabecular density was found ($p > 0.2$).

Conclusion: CaSupp reconstructed from DLCT enable visualization and detection of BME in traumatic fractured vertebrae with high diagnostic accuracy using CaSupp-I of 70–100.

1. Introduction

Vertebral fractures (VF) are common and require individual treatment as they are associated with considerable morbidity, mortality and future VF [1–4]. A precise diagnostic workup of VF is therefore crucial for adequate clinical management.

Magnetic resonance imaging (MRI) is the reference standard for the visualization of posttraumatic bone marrow changes since fluid sensitive sequences combined with T1-weighted sequences allow for the differentiation of acute and chronic VF based on the presence or absence of bone marrow edema (BME) [5,6]. However, MRI has the following limitations: trabecular and cortical bone structures are not sufficiently visualized, MRI may not be possible due to claustrophobia, implants (cardiac pacemakers, etc.) or the need for short examination times (pain, motion artifacts, etc.) [7].

In clinical routine, X-ray and CT of the spine are performed in initial assessment of VF. Opposed to MRI, these modalities visualize high contrast tissues, whereas low-contrast tissues such as bone marrow are obscured due to the use of high photon energies and due to superposition (X-ray) and partial volume effects of trabecular bone (CT). In X-ray and conventional CT, many VF may remain occult due to low bone mineral density (BMD), subtle lesions or the lack of trauma in

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patient history [8,9]. Thus, VFs are radiologically underdiagnosed in up to 50% of the cases [8,10].

Dual-energy CT (DECT) has been shown to enable radiologists to assess both, high contrast (trabecular bone) and low contrast tissues (bone marrow) in one examination [11]. This is enabled by subtraction of calcium from the reconstructed images through material separation, as distinct materials attenuate photons dependent on their energy differently [11]. Bone marrow changes, normally obscured by the dense trabecular bone, may be visualized and therefore allow for the detection of traumatic BME [11]. Previous studies demonstrated good diagnostic accuracy of similar techniques using dual-source CT (DSCT) [12–15]. Dual-layer detector CT (DLCT), which registers the photons of lower energy in the inner layer of the detector and the photons of higher energy in the outer layer of the detector, has recently been introduced as an alternative approach to DECT and is thought to have a technical disadvantage in separation of the two energy spectra due to a higher spectral overlap [11,16]. However, other factors besides the energy separation also contribute to material separation capability [16]. DLCT is the only approach to DECT offering perfect spatial and temporal consistency between the two spectral measurements as well as employing a projection-based spectral decomposition, which fully incorporates beam hardening effects [17]. Further, DLCT allows for reconstruction of images in which calcium has been subtracted, while the extent of calcium subtracted can be modified using different calcium suppression indices (CaSupp-I).

Thus, the purpose of this study was to investigate the diagnostic accuracy of calcium suppressed images (CaSupp) reconstructed from dual-layer detector computed tomography (DLCT) for the detection of bone marrow edema (BME) in vertebral fractures. Additionally, we compared calcium suppressed images reconstructed at different calcium suppression indices (CaSupp-I) in order to determine the calcium suppression indices yielding the maximum contrast and thus the best assessment of bone marrow edema.

2. Material and methods

2.1. Study population

The study was approved by the institutional review board. Written informed consent was waived due to the retrospective design of the study. Out of all patients examined using the DLCT from May, 1st 2016 to April, 30th 2017 (n = 4654) we retrospectively identified 451 patients (9.7%) who were diagnosed with a fracture (Fig. 1). Out of these patients we collected those with a vertebral fracture (n = 163; 3.5%) and further examined those, who had undergone complementary MRI within one week (n = 52; 1.1%)). 12 patients (0.3%) with metastatic disease and 6 patients (0.1%) with artifacts due to metal implants were excluded from the study. The remaining 34 patients (0.7%) were included in the study.

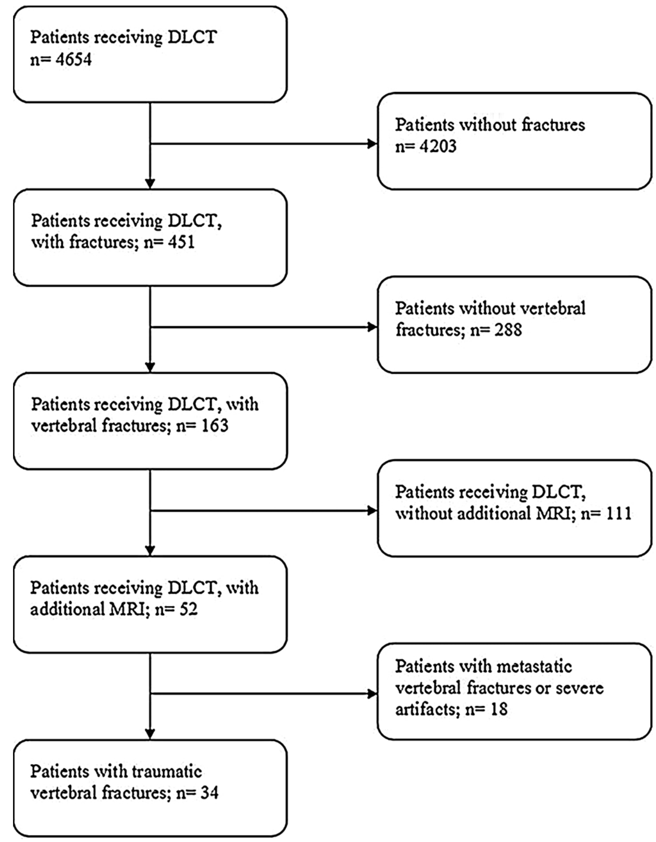

Fig. 1. Flowchart showing the selection of the study population.

2.2. CT imaging and image reconstruction protocols

All examinations were performed on a dual-layer detector CT (Spectral IQON®, Philips Healthcare, Best, the Netherlands). CTs were performed with the following acquisition parameters: tube voltage 120 kVp, automated attenuation based dose modulation (DoseRight, Philips Healthcare), rotation time 0.33 s, pitch 0.671, collimation 64 × 0.625, slice thickness 1 mm and an increment of 0.5 mm.

Conventional images were reconstructed using iDose4 ((level 2), Philips Healthcare) and a sharp kernel (kernel C). In addition, spectral base images were reconstructed using Spectral ((level 2), Philips Healthcare) and a sharp kernel (kernel C).

From the spectral base images, HU-based images were reconstructed with a calcium suppression algorithm, which uses the acquired data to suppress calcium that normally overlays the underlying tissues. In these images, the calculated calcium component of the attenuation is removed resulting in virtual HU as similar as possible to the expected HU that would have been obtained without calcium contribution to the attenuation.

This algorithm uses a material re-composition process in which the spectral base images are converted into sets of dynamic material pairs – soft tissue and a material – with a user-defined level of calcium composition that is indicated by the CaSupp-I. The CaSupp-I can be adjusted on a scale from 25 to 100. A high CaSupp-I targets tissues with a high calcium composition weight; a low CaSupp-I, targets tissues with a low calcium composition weight.

2.3. MR imaging protocol

MRI was conducted on a 3-T MR unit (Ingenia, Philips Healthcare). The imaging protocol included a T1-weighted turbo spinecho sequence in the sagittal plane with a time to repetition of 1000 msec, a time to echo of 10 msec, a slice thickness of 3 mm, a gap of 0,3 mm, a field of view of 200 × 300 × 66 mm^3 and a matrix of 224 × 296 as well as a short tau inversion recovery sequence (STIR) in the sagittal plane with a time to repetition of 1400 msec, a inversion recovery delay of 200 msec and a time to echo of 70 msec, a slice thickness of 3 mm, a gap of 0,3 mm, a field of view of 200 × 300 × 66 mm^3 and a matrix of 224 × 263.

2.4. Image analysis

MRI served as standard of reference for the detection of traumatic vertebral bone marrow edema. A blinded reader (V.N.) with 4 years of experience in musculoskeletal radiology evaluated the MRI. Traumatic vertebral BME was defined as hyperintensity in STIR and hypointensity in T1-weighted sequences [5,6] (Fig. 2). A second blinded reader (N.A.) with 4 years of experience in musculoskeletal radiology determined fractured vertebrae in the conventional CT-images [18].