Relationships between diffusion weighted signal intensity, ADC and water/fat content of malignant bone marrow

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Background

Diffusion weighted (DW) MRI is clinically used to detect bone marrow (BM) malignancy because of its sensitivity to tumor cell density, high nuclear-cytoplasmic ratio, the relative amounts of adipocytes and marrow cells, water content and perfusion[1]. Non-linear, non-inverse relationships between DW signal intensity (SI) and apparent diffusion coefficient (ADC) values have been shown in BM breast cancer and myeloma lesions[2]; no such data exists for other tumor types. Additionally, it is unknown how the relative composition of BM fat, water and cellularity affects DW-SI and ADC values[3].

Purpose

To observe the relationships between BM water/fat composition, ADC, and high b-value image SI in normal and malignant bone marrow and the differences between these parameters in different tumor types.

Methods

Subjects: A retrospective analysis of 92 patients (with 224 lesions) undergoing WB-MRI scans was performed. Five cohorts of patients with untreated/relapsed malignant bone marrow disease were identified: (1) 27 with breast cancer (75 ROIs), (2) 5 with renal cell carcinoma (9 ROIs), (3) 3 with melanoma (6 ROIs), (4) 20 with prostate cancer (49 ROIs) and 16 with myeloma (43 ROIs). Malignant disease was compared with 21 patients with no morphologic evidence of bone marrow disease (42 ROIs).

MRI imaging: Patients were scanned on a 1.5T scanner (Avanto, Siemens Healthcare) equipped with multiple surface coils. Patients had WB studies (vertex to mid-thighs) done in the following sequence order: (1) T1-weighted, gradient-echo axial 2-point Dixon sequence that generated four image-sets [in-phase, opposed phase, water-only (WO), and fat-only (FO)]; (2) T2-weighted, short-tau inversion recovery (STIR) axial images with half-Fourier single-shot turbo spin-echo (HASTE) readouts; (3) WB-DWI was performed using free breathing, inversion recovery, single shot spin-echo echo-planar sequences in 4 stations (5mm slices, 50 slices/station). In 7 patients we used diffusion sensitizing gradients with b-values of 50 and 800s/mm^2 and in 85 we used b-values of 50 and 900s/mm^2.

Data analysis: ADC values were calculated by vendor software using mono-exponential fitting to the b-values. The following regions of marrow in the lower lumbar spine and pelvis were prospectively identified by a trained radiologist: normal yellow bone marrow (YBM), mixed red bone marrow (mRBM), bone metastases and diffuse bone marrow infiltrations. Following image selection, hand-drawn regions of interest (ROI) were placed on the high b-value images and mean SI (arbitrary units - AU) and ADC (μm^2/s) values were recorded. Corresponding mean image fat SI (AU) on FO images and mean image water SI (AU) on WO images were recorded.

Statistical analysis: High b-value SI values were normalised to the psoas muscle SI (muscle-normalized SI; nSI). Comparisons were done using descriptive statistics, scatter plots, non-parametric statistical tests, ROC, spread plots and non-linear regression analyses.

Results

Normal bone marrow (YBM/mRBM) ADC values were lower than tumors (p <0.0001; AUC 0.97; cut-off 765μm^2/s). nSI and image water:fat ratios of normal BM were also lower than tumors (nSI: p<0.0001; AUC 0.97; cut-off 3.1AU; water:fat ratio: p<0.0001; AUC 0.99; cut-off 1.1). Second order polynomial curve fitting between nSI and water:fat ratio with ADC had correlation coefficients (R^2) of 0.21 (Fig1) and 0.19 respectively. The 95th centile for mean tumor ADC value was 1433μm^2/s. There was a linear relationship between nSI and water:fat ratio in normal bone marrow only (R^2 0.64). There were significant differences in the nSI between prostate cancer metastases and myeloma (p=0.03) and breast lesions (p<0.0001) (Fig2) but not in ADC values nor water:fat ratios.

Discussion and conclusions

The known differences in the cellularity of normal and malignant bone marrow are reflected in the SI of high b-value DW images, in ADC values and water:fat ratios. The polynomial relationships between both DW-SI and water:fat ratio with ADC values is independent of tumor type; this provides an opportunity to select a generally applicable upper ADC threshold for untreated disease (between 1400-1500μm^2/s). The nSI difference on high b-value images between prostate metastases and breast/myeloma lesions maybe ascribed to the greater preponderance of osteosclerotic lesions in untreated prostate cancer.
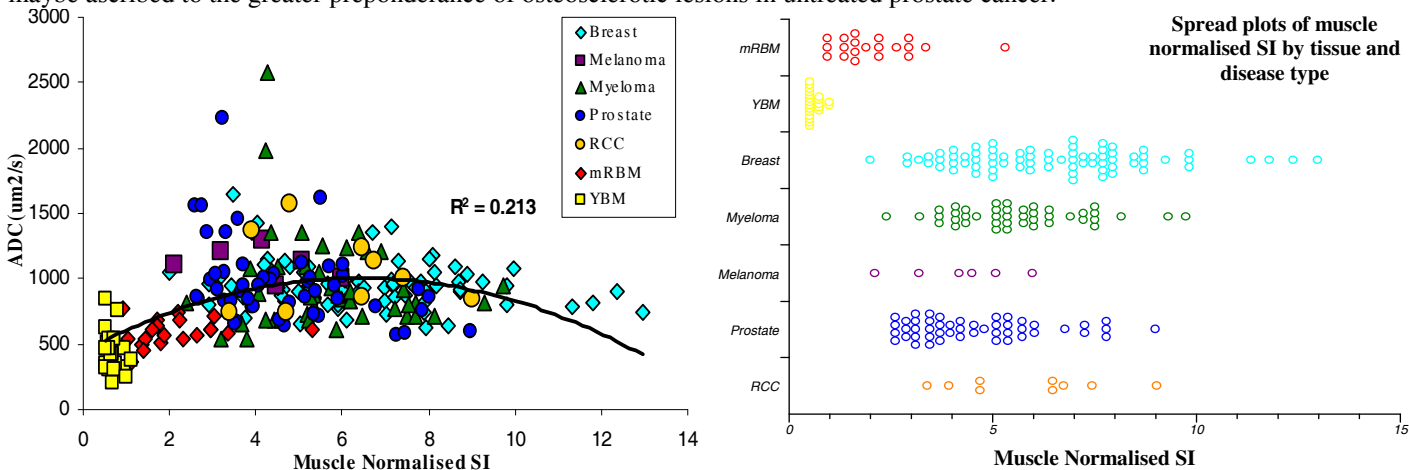
References: 1. Biffar A, et al. *Eur J Radiol* 2010;76:323-328. 2. Padhani A R, et al. *AJR* 2013; in press. 3. Nonomura Y, et al. *J Magn Reson Imaging* 2001;13:757-760