Diffusion weighted imaging of bone marrow : comparison of apparent diffusion coefficients of normal bone marrow and metastatic bone disease to inform the development of a protocol optimised to metastatic bone disease

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Introduction

The role of diffusion weighted (DW) MRI in imaging of soft tissue tumours had evolved rapidly[1]. However its application to bone disease has not yet been fully exploited because the unique microarchitecture of normal and pathological bone marrow present challenges. DWI has been explored for identifying bone metastases and to differentiate benign from pathological vertebral fractures[2]. Feasibility studies also indicate that DWI in bone may provide a much needed quantitative index of response to treatment[3].The aim of this study was to identify the apparent diffusion coefficient (ADC) of normal bone marrow and bone metastases in order to develop a DW MRI protocol optimised to bone.

Methods

Lumbar spine and pelvis of 13 healthy volunteers were scanned using a twice refocused spin echo DW sequence (selected to minimise eddy current distortions[4]): Siemens Avanto 1.5T, axial plane, slice thickness 5mm, TR 3000ms, TE 80ms, 4 averages, 3 orthogonal directions and b values of 0, 50, 100, 250, 500 and 750 smm^{-2} with fat saturation.T1 and T2W images of the lumbar spine and pelvis were acquired for correlation. ADC maps were generated using all 6 b values using the system software. For each volunteer a $2.3cm^2$ ROI was placed in L5 and right and left iliac bones. 33 patients with bony metastatic or myeloma bone disease (confirmed by bone scan/marrow aspirate) were scanned with the same protocol and ROIs drawn around tumour on the ADC maps - 23 metastatic prostate cancer (71 lesions), 5 myeloma bone disease (33 lesions), 3 metastatic breast cancer (19 lesions), 1 thyroid cancer (2 lesions), 1 endometriod cancer (2 lesions). Corresponding plain films and CT scans were used to document whether disease was lytic, sclerotic or diffuse – where this was not available a correlation was not made (n=14). Diffuse disease was defined as diffuse MR signal abnormality without plain film/CT features of sclerosis/lysis. 55 lesions were sclerotic, 39 lytic and 19 diffuse.

Results

From the 3 ROIs the mean ADC of marrow in 13 normal volunteers (4 male, 9 female; age range 26-54; mean age 38.5) was 557.7+/- 122$mm^2s^{-1}X10^{-6}$. Mean ADCs for sclerotic, lytic and diffuse disease were: 793.6 +/-128; 1529 +/-533; 857.9 +/- 188 $mm^2s^{-1}X10^{-6}$. Mean ADCs for bone marrow pathology were all significantly different ($p<0.05$) from the mean ADC of normal marrow.

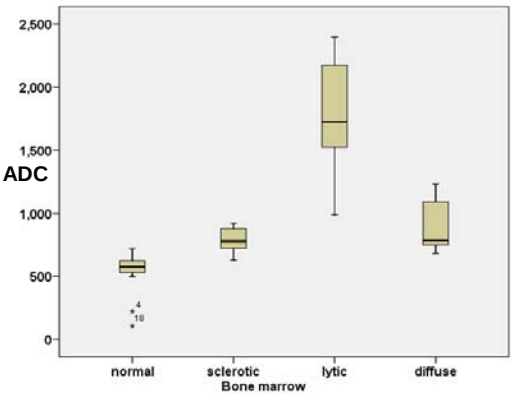
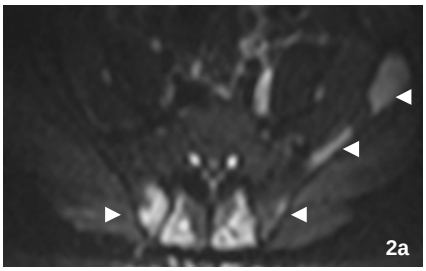
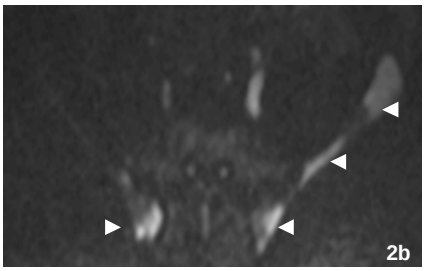


Fig 1. Boxplot showing ADCs ($mm^2s^{-1}X10^{-6}$) of normal marrow and sclerotic, lytic and diffuse bone marrow pathology.





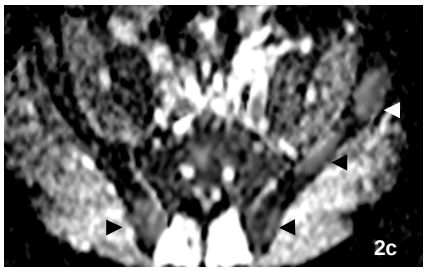


Fig 2a and **b**: b50 and b1400 smm^{-2} DW MRI demonstrating lymphoma deposits (arrows) involving the bony pelvis. **2c** shows the corresponding ADC map generated from b 0, 50, 750, 1300, 1400 $smm^{-2.}$ Four discrete foci of disease in the iliac bones are shown by the ADC map to have higher ADCs than normal marrow.

The contrast between normal and pathological marrow can be defined by [5]:

$$b_{opt} = \frac{1}{D_m - D_b} ln\left(\frac{D_m}{D_b}\right)$$

where b*opt* = optimal b value, D*m* = ADC of pathology, D*b* = ADC of normal background marrow. From our data the optimal b value for differentiating normal marrow and sclerotic metastases is 1496 smm^{-2}, lytic metastases 1038 smm^{-2} and diffuse disease 1434 smm^{-2}. For all pathological marrow (mean ADC for pathological marrow 1057.8 +/-477$mm^2s^{-1}X10^{-6}$) the optimal b value was 1279 smm^{-2}.

Discussion

The increased cellular density of soft tissue tumours makes them conspicuous to DW MRI as areas of restricted diffusion relative to normal surrounding tissues. This relationship is inverted in bone marrow which is significantly restricted compared to marrow pathology of various types. Metastatic marrow pathology disrupts and replaces the normal marrow architecture with an ADC increase. In sclerotic metastases where trabecular thickening and development of new bony struts are seen the increase in ADC is possibly due to osteoclast activity [6,7]. Given the increase in ADC in metastatic bone disease, optimised contrast can be obtained using higher b values. We suggest a protocol with a maximum b value of 1400 smm^{-2} (Fig 2).

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