Diffusion coefficients and the perfusion fraction of colorectal hepatic metastases estimated using single-shot echo-planar sensitivity–encoded (SENSE) diffusion-weighted MR imaging

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Introduction: Motion related imaging artifacts in diffusion-weighted imaging (DWI) can be reduced using breath-hold single-shot echo-planar sensitivity-encoding (SENSE) technique. Visual assessment of single shot echo-planar SENSE diffusion-weighted images acquired with varying gradient factors (*b* values) has been shown to be more sensitive than superparamagnetic iron-oxide contrast-enhanced MR imaging in detecting liver metastases [1]. However, both metastases and benign lesions, such as hemangioma, demonstrate restricted diffusion at higher *b* values and may be indistinguishable by visual assessment alone. DWI performed using different *b* values allows quantitative estimates of apparent diffusion coefficient, true diffusion coefficient and perfusion fraction of metastases to be derived [2]. Quantitative assessment can add confidence to the diagnosis of hepatic malignancy [3] and may be of value in patient follow up.

Purpose: To estimate the apparent diffusion coefficient (ADC), 'true' diffusion coefficient (D) and perfusion fraction (PF) of hepatic metastases arising from colorectal carcinoma using breath-hold single-shot echo-planar SENSE-DWI with three gradient factors (*b* values).

Materials and Methods: 16 patients with 33 hepatic metastases arising from colorectal carcinoma were evaluated. There were 12 men and four women (mean age =52 years; range: 43 to 69 years). The mean size of metastasis was 21 mm. MR imaging was performed on a 1.5T system (Intera, Philips Medical System, Best, Netherlands) using a SENSE phased-array body coil. Following routine T1 and T2-weighted axial imaging of the liver, DWI of the entire liver was performed axially using breath-hold single-shot echo-planar imaging. Twelve sections were acquired during each 20 seconds breath-hold (TR = 1850 ms, TE =56 ms, gradient strength = 30 mT/s, 7 mm section thickness, slice gap = 1 mm, single acquisition, 340 cm FOV, Matrix = 112 x 256, SENSE factor = 2) and examination of the entire liver was usually completed in two breath-holds. Diffusion gradients with three *b* values (0, 150 and 500 sec/mm^2) were applied along three directions: phase encoding (P), frequency encoding (M) and section-select (S). The second *b* value of 150 sec/mm^2 was chosen because it was shown to visibly null flow within hepatic vessels. Quantitative maps of diffusion coefficients were generated using the Intera Workstation (Release 9, Philips Medical System). For each patient, an index isotropic ADC map was generated using the *b* = 0, 150 and 500 sec/mm^2 images. An index isotropic map reflecting the 'true' diffusion coefficient (D) was generated using only the *b* = 150 and 500 sec/mm^2 images. These maps were analysed by consensus by two readers. In each patient, an identical region of interest (mean 125 pixels) encompassing a metastasis (n = 33) was placed on the ADC and D maps and their values recorded. Two values of ADC and D were obtained for each metastasis and the average computed. Identical regions of interest (mean 216 pixels) were randomly placed across normal appearing liver (n = 59), taking care to avoid large vessels. For each normal liver area, the average of two readings of ADC and D was computed. The mean ADC and D of normal liver and metastases were compared using the Student's t-test. The PF of normal liver and metastases was also calculated and compared using the t-test.

Results: The mean ADC value of normal hepatic parenchyma and metastases (1.52 x 10^{-3} mm^2/sec) was found to be significantly higher than the mean D value (1.17 x 10^{-3} mm^2/sec) ($p < 0.001$, paired t-test). Metastases were shown to have a higher mean D value compared with normal liver ($p = 0.001$, t-test). However, no significant difference was found between the mean ADC values of metastases compared to normal liver ($p = 0.11$, t-test). The estimated mean PF was significantly lower in metastases (0.17) compared to normal liver (0.29) ($p = 0.001$, t-test) [Table 1]. The box-plots of the ADC and D values of normal liver and metastases are as show in Figure 1. The box-plots of the PF values of normal liver and metastases are shown in Figure 2.

Discussion: Using single-shot echo-planar SENSE-DWI, the entire liver could be evaluated in less than 60 seconds without the administration of contrast medium. It was possible to derive quantitative indices of ADC, D and PF by using just three *b* values. The ADC value incorporates effects of both diffusion and micro-capillary perfusion [3] and not surprisingly, was significantly higher than the D value, which was derived from only the *b* = 150 sec/mm^2 and 500 sec/mm^{2}images. Although metastases demonstrated a significantly higher D value compared with normal liver, this difference was not detectable in the ADC value, due to summation of the effects of perfusion and diffusion within each voxel. Metastases were found to have a lower PF, in agreement with the view that colorectal hepatic metastases are hypovascular compared to normal liver.

Conclusions: An estimate of ADC, D and PF may be derived using breath-hold single-shot echo-planar SENSE-DWI with just three gradient factors (*b* values). Colorectal metastases demonstrated a significantly higher diffusion coefficient (D) but lower perfusion fraction (PF) compared with normal liver parenchyma.

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References: [1] Nasu K et al., 89th Assembly meeting of RSNA, 2003. [2] Yamada I et al., Radiology1999; 210:617-623. [3] Taouli B et al., Radiology 2003; 226:71-78. [4] Le Bihan D et al., Radiology 1988; 168:497-505.

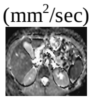
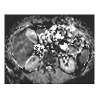
	Mean ADC (mm^2/sec) 	**Mean D** (mm^2/sec) 	**Mean PF**
Normal liver	1.39 x 10^{-3}	1.01 x 10^{-3}	0.29
Metastases	1.49 x 10^{-3}	1.24 x 10^{-3}	0.17
	P = 0.11	P = 0.001	P = 0.001

Table 1. Mean ADC, D and PF values of normal liver and metastases

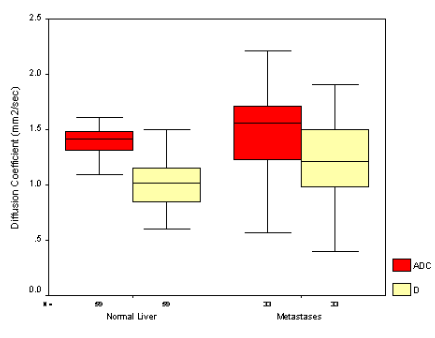


Figure 1. Box-plots of the ADC and D values of normal liver and metastases.

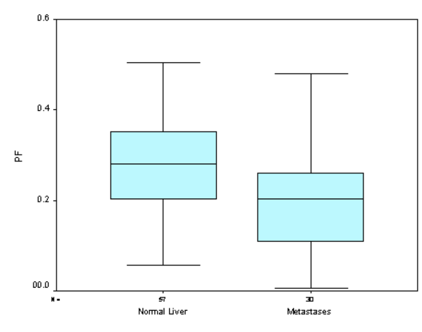


Figure 2. Box-plots of the PF values of normal liver and metastases.