Hepatic steatosis results in a reduction in the apparent diffusion coefficient (ADC) of liver parenchyma

O. Wignall[1], E. Scurr[1], D. Collins[2], C-H. Thng[3], and D-M. Koh[2]

[1]Radiology Department, Royal Marsden Hospital, Sutton, Surrey, United Kingdom, [2]CR UK Clinical Magnetic Resonance Research Group, Institute of Cancer Research, Sutton, Surrey, United Kingdom, [3]Department of Diagnostic Imaging, National Cancer Centre, Singapore, Singapore

Introduction

Single shot echo-planar diffusion-weighted MRI (DWI) is used to detect and characterise liver disease. Recently, DWI has been shown to be a potential tool for evaluating and quantifying liver fibrosis, which results from chronic liver disease and cirrhosis [1] . The apparent diffusion coefficient (ADC) of liver parenchyma decreases with increasing grades of fibrosis [1]. Hepatic fat infiltration is also common in patients with chronic hepatitis and cirrhosis, but the relationship between steatosis and liver ADC measurements has not been previously ascertained. We hypothesize that hepatic steatosis can also lead to a reduction in liver ADC.

Purpose

The purpose of this study was to compare the ADC measured from liver parenchyma in areas with and without fat infiltration as determined by in-phase and opposed-phase T1-weighted MR imaging.

Materials and Methods

Liver DWI, in-phase and opposed-phase T1-weighted imaging are performed as part of our routine and research liver imaging protocol. A retrospective review of 156 cases of liver MRI performed at 1.5T in the past year revealed 18 cases of hepatic steatosis on T1-weighted in-phase and opposed-phase imaging *(TR =128 ms, TE =4.6 and 2.3 ms, 450 cm FOV, 256 x 256 matrix, α = 80°, SENSE factor 1.8, section thickness 7 mm)*. 18 cases without visible fat infiltration were also randomly chosen for comparison. Free breathing single-shot echo-planar fat-suppressed diffusion-weighted images *(TR = 2500, TE = 72 ms, 340 mm FOV, 112 x 256 matrix, images re-interpolated to 256 x 256 matrix, 7 mm thickness, SENSE factor 2, Nex =5)* were acquired using gradients applied in three orthogonal directions and 6 b-values (0, 50, 100, 250, 500 and 750 s/mm^2).Trace images were used to generate ADC maps.

The in/opposed-phase T1-weighted mages and ADC maps were reviewed in consensus by two experienced radiologists. Hepatic steatosis was identified in areas showing signal attenuation on opposed-phase T1-weighted imaging [2] and polygonal regions of interest (ROIs) were drawn, avoiding intra-hepatic vasculature and segment II of the left lobe, to record their mean signal intensities (*SI opposed*). The ROIs were copied onto T1-weighted in-phase images and ADC maps to record their mean values (*SI in and ADC fat*). The percentage fat infiltration was estimated by calculating the *SI ratio (fat)* as follows: *[(SI in – SI opposed)/ (SI in + SI opposed) x 100%]*. The process was repeated for areas of fat sparing and apparently normal liver parenchyma to obtain the *SI in, SI out, ADC normal* and *SI ratio (normal)*. The ADC and SI ratio distribution was asymmetric (D'Angustino Pearson Test, $p > 0.05$). *ADC fat* and *ADC normal* were compared within and between patients using non-parametric statistical rank tests. Linear regression was performed to determine the relationship between *ADC fat* and *SI ratio (fat).* For all analyses, a p-value of < 0.05 was taken to be statistically significant.

Results

Of the 18 patients with fat infiltration, 7 showed geographical or focal patterns (***Figure 1***), while 11 showed diffuse steatosis. 26 ROIs were drawn in areas showing fatty change, and 9 ROIs were drawn over areas of fat sparing on the same image slices. In the 18 patients with non-fatty appearing liver, 18 ROIs were drawn over normal liver parenchyma. The mean signal intensity ratio of hepatic steatosis was 26% (95% CI: 19-33%) compared with 4% (95% CI: 2.3 – 5.1%) in normal appearing liver parenchyma ($p < 0.001$, Mann-Whitney test). The mean ADC of hepatic steatosis was significantly lower compared to normal appearing liver parenchyma within (1.32×10^{-3} mm^2/s versus 1.42×10^{-3} mm^2/s, $p = 0.04$, Wilcoxon signed test) and between patients (1.33×10^{-3} mm^2/s versus 1.40×10^{-3} mm^2/s, $p = 0.04$, Mann Whitney test). In areas of hepatic steatosis showing *SI ratio (fat)* > 10 %, there was a linear regression relationship between *ADC fat* and *SI ratio fat* ($r^2 = 0.22$, $p = 0.024$) (***Figure 2***). No significant relationship was found between *ADC normal* and *SI ratio normal* ($r^2 = 0.01$, $p = 0.556$).

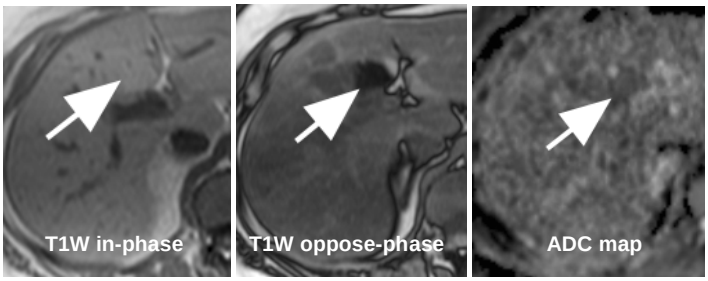

Figure 1. *Opposed-phase T1 weighted imaging shows geographical signal attenuation throughout liver, but also a more focal area of signal loss (arrows) due to focal steatosis. Note reduced ADC in area of focal steatosis (arrow).*

Discussion

We hypothesize that fat deposition in the liver, both between and within hepatocytes, can restrict the free diffusion of water, leading to reduction in ADC compared with non-steatotic liver parenchyma. This was observed in our study. Steatosis is common in patients with chronic liver disease, and future developments in using DWI to quantify liver fibrosis may have to take into account the presence of fat to ensure accurate assessment. In addition, steatosis may also reduce the 'contrast' between the liver and solid liver lesions, making pathologic lesions more difficult to identify on ADC maps.

In our study, we found an inverse linear relationship between the ADC and the SI ratio in steatotic liver with a SI ratio > 10%. However, using SI ratio to quantify liver fat may be inaccurate since the technique does not take into account phase shifts and T2* effects [3]. Future prospective studies using more accurate methods of fat quantification (e.g. Dixon technique) would be useful to validate our current findings, and to determine more precisely the relationship between ADC and percentage fat deposition.

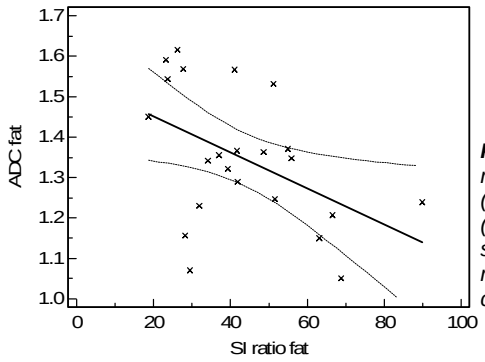

Figure 2. *Linear regression relationship between ADC (x 10^{-3} mm^2/s) and SI ratio (%) in areas of hepatic steatosis. Dotted lines represent the 95% confidence intervals.*

Conclusions

Hepatic steatosis results in a reduction in the ADC of liver parenchyma and has implications for the use of DWI in the evaluation of liver disease.

References

[1] Tauoli B et al. AJR 2007; 189:799-806
[2] Hussain HK et al. Radiology 2005; 237(3):1048-55
[3] Matsunaga S et al. Medical imaging and information science 2006.

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