Z-spectrum asymmetry : from 3T to 7T

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Introduction:

Magnetization Transfer and technically related effects such as CEST are important sources of contrast in MRI. Studying MT in vivo at 7T is challenging due to the increase in longitudinal relaxation time and SAR limits. To overcome this, we use pulsed saturation with EPI readout (MT-EPI) to measure MT at a range of offset frequencies and on the approach to steady-state in a reasonable imaging time. We have used these to compare the z-spectrum at 7 and 3T and investigate its asymmetry, as well as the sensitivity of MT at high field.

Method:

Scanning was carried out on Philips Achieva scanners at 3 and 7T. The sequences consisted of a train of up to 20 off-resonance pulses (13.5 μT Gaussian-windowed, sinc pulses with a bandwidth from 110 Hz to 300 Hz, 55 ms between each pulse), followed by a EPI readout (EPI: single shot, TR/TE=10000/16ms, 2x2x2mm^3). Pulsed saturation is less efficient and broader bandwidth than CW saturation but is readily implemented on standard scanner hardware. For the MT-EPI sequence [1], the frequency offset of the saturation pulses was varied from -10 to +10 kHz in a logarithmic way, allowing the MT spectrum to be measured in < 5 min for 24 measurements. MT ratio (MTR) maps were calculated and MT asymmetry (MT_{asym}) maps were calculated by taking the different between MTR maps acquired with positive and negative off-resonance pulse trains, divided by the positive off resonance train image. Z spectra and asymmetry spectra were also computed for white matter regions of interest. The data were corrected for the effects of B_0 inhomogeneities and eddy currents by shifting the spectra on a pixel-by-pixel basis according to an acquired Bo map (acquired with same parameters as the MT-EPI data), and then correcting for the average offset of the Bo map. Healthy subjects (N=4) were scanned in accordance with approval from the local ethics committee

Results:

Figure 1 shows the variation in the z-spectrum with saturation pulse bandwidth at 7T. As the bandwidth of the MT pulses decreased, the MT effect decreased, but the spectral resolution (particularly of the CEST peak at around 3.5ppm) is increased as expected. Figure 2 shows the spectra acquired at 3T and 7T for two different numbers of saturation pulses. These spectra are plotted in Hz to match direct saturation effect between fields. The MT effect is larger at 7T than 3T: at +1100 kHz off resonance there is an 1.2-fold increase (26% vs 32%) in MTR between 3T and 7T for a train of 20 pulses and a bandwidth of 300Hz. Figure 3 shows MTR images acquired at 7T and good grey/white matter contrast can be seen at positive offset (A and D), negative offset (B and E) and MTRasym images (C and F). The insert of the figure 2 shows the asymmetry between negative and positive off-resonance saturation. It reached a (negative) peak of 9% at 7T close to 4 ppm, whereas it was around 2.5% at 3T.

Discussion:

The z-spectrum and approach to saturation [1] has been measured in a reasonable imaging time at 7T, which will allow MT parameters to be quantified in vivo at 7T. MT contrast is increased at 7T and this will translate into a significant increase in CNR clinically. Moreover sensitivity to CEST effects, generally associated with amide protons (at 3.5ppm) [3], is considerably increased at 7T. This increased sensitivity is at least in part because of increased spectral resolution due to higher resonance frequency, but may also relate to a differential increase in longitudinal relaxation times as well as the decrease in transverse relaxation times. This increase in CEST sensitivity opens up the possibility of measuring pH in vivo at high resolution. This MT asymmetry may provide a novel source of contrast, but may also confound some experiments such as CASL. Quantitative MT data must be corrected for B1 and Bo inhomogeneities particularly at 7T.

[1]: Tyler, Gowland. Magn. Reson. Med. 2005; 53:103-109. **[2]:** Henkelman et al, Magn. Reson. Med., 1993; 29: 759-766. **[3]:** Hua et al, Magn. Reson. Med., 2007; 58: 786-793.

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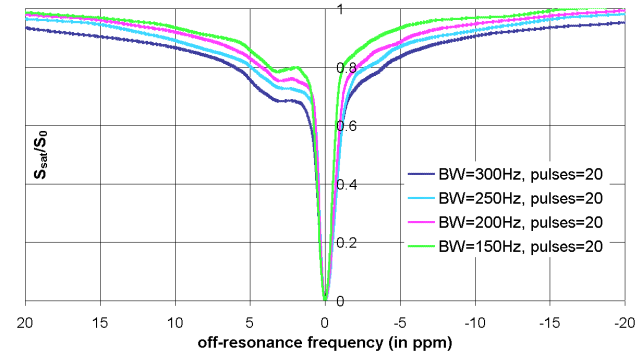

Fig. 1: Z-spectrum at 7T, showing a large asymmetry, especially around the amide peak at 3ppm.

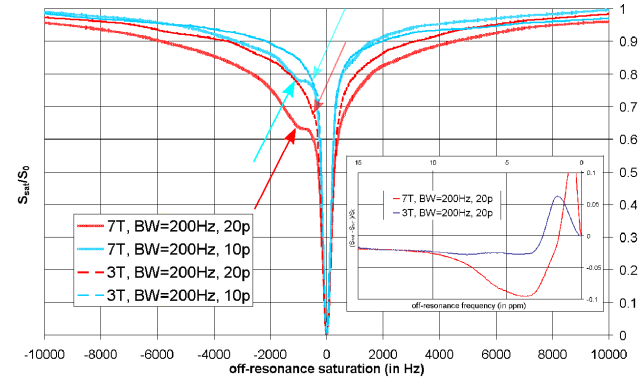

Fig. 2: Z-spectrum at 7T versus 3T, showing less MT effect at 3T compared to 7T at the same off-resonance frequency. Up and down arrows shows the amide peak at 7T and 3T. Enclose is the asymmetry spectrum for 3T (blue) and 7T (red).

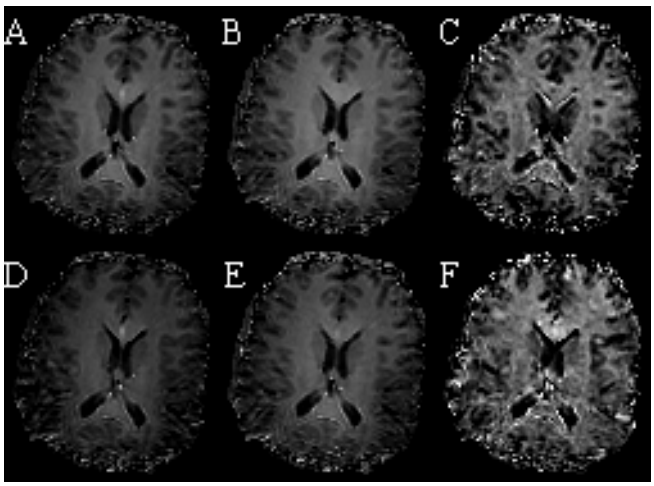

Fig. 3: MT ratio images at negative offset (A: -970Hz and D -1300Hz) and positive offset (B: 970Hz and E 1300Hz) for a saturation of 20 pulses and a bandwidth of 300Hz. C and F are the corresponding MT_{asym} image, respectively 970 and 1300Hz.