Retrospective motion correction in CEST MRI data using time domain analysis

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TARGET AUDIENCE: Researchers and clinicians interested in CEST MRI and/or MRI motion correction

PURPOSE: Chemical exchange saturation transfer (CEST) is a particularly promising technique for detecting low concentration endogenous compounds or exogenous agents [1] using MRI. However, in vivo CEST studies of the abdominal region are often hampered by signal fluctuations from motion. In a given region, this signal variation can be an order of magnitude larger than the CEST signal. Extracting CEST information in the presence of motion is challenging and hence has limited CEST studies for many organs (e.g., kidney, liver). Time-domain analysis of CEST data (TRIM) has previously been used to remove nuisance signals from direct water saturation and conventional magnetization transfer [2]. Here, we demonstrate that this approach can be used to significantly reduce motion effects in z-spectra using simulated data from pilot swine experiments at 3 T using the Arginine based pH nanosensors we have described previously [3].

METHODS: CEST MRI data was simulated using the Bloch-McConnell equations [4] for a solute proton pool 2 ppm from the water resonance with an exchange rate of 1000 s^{-1} (Fig. 1a). To approximate the effect of respiratory motion, we convolved the CEST data with a sinusoidal modulation of amplitude comparable to the maximum CEST signal (Fig. 1b). The convolved data (Fig. 1c) was Fourier transformed (Fig. 1d) and the peak corresponding to motion identified (j = 10 in Fig. 1d). This peak was subsequently nulled (Fig. 1e) and the data transformed back to the CEST frequency domain (Fig. 1e). The CEST signal was quantified using MTR asymmetry ($MTR_{asym} = [S_{sat}(-\Delta\omega) - S_{sat}(\Delta\omega)] / S_0$). One requirement of the TRIM procedure is to ensure the signal modulation is appropriately sampled (Nyquist limit).

In vivo experiments were performed on a swine abdomen at 3 T. The hepatic artery was selected via femoral access under x-ray angiography guidance. DSC MRI with intra-arterial feromoxide nanoparticles injection was used to visualize the perfused region of the liver and subsequently, arginine capsules [3] were selectively infused into the liver lobe. As a reference, capsules were also injected into a dorsal muscle. CEST experiments were performed with a 4 s presaturation pulse (amplitude= 2.4 μT) and followed by fast spin-echo (FSE) readout.

RESULTS For the simulated data, the original and motion-corrected spectra are compared in Fig. 1f. There is very little difference between the original simulated data and the TRIM processed data after the addition of motion-like effects (mean difference = 0.15%). The CEST signal quantified using MTR_{asym} was 2.5% in the original data and 2.3% in the processed data.

Fig. 2a shows a CEST Z-spectrum acquired from a region of interest in the swine abdomen. There is a clear signal modulation in the Z-spectrum, which is attributed to abdominal motion. Using MTR asymmetry, determining the CEST signal is unreliable since the MTR_{asym} curve modulates between -10% and 7%. This modulation is eliminated using TRIM motion correction and thus the signal due to the arginine capsules (at ~2 ppm) can be extracted from the CEST data. Fig. 2b-c show CEST maps corresponding to the frequency of the arginine capsules. The corrected map generated using the TRIM approach (Fig. 2c) shows a clear outline of the liver and this highlighted region to a subsequent ferumoxides-enhanced DSC perfusion scan. The location of the implanted capsules in the dorsal muscle is also easily seen in Fig 2c.

CONCLUSION: We have shown how motion effects in z-spectra can be removed retrospectively using the simple and easy to implement time-domain based TRIM procedure. This technique can potentially open many new applications for body CEST MRI that were previously limited by motion effects.

REFERENCES: [1] van Zijl and Yadav. Magn Reson Med 2011;65:927-948. [2] Yadav et al. Magn Reson Med 2013;70:547-555. [3] Chan et al. Nat Mater 2013;12:268-275. [4] McConnell. J Chem Phys 1958;28:430-431. Funding: R01EB012590

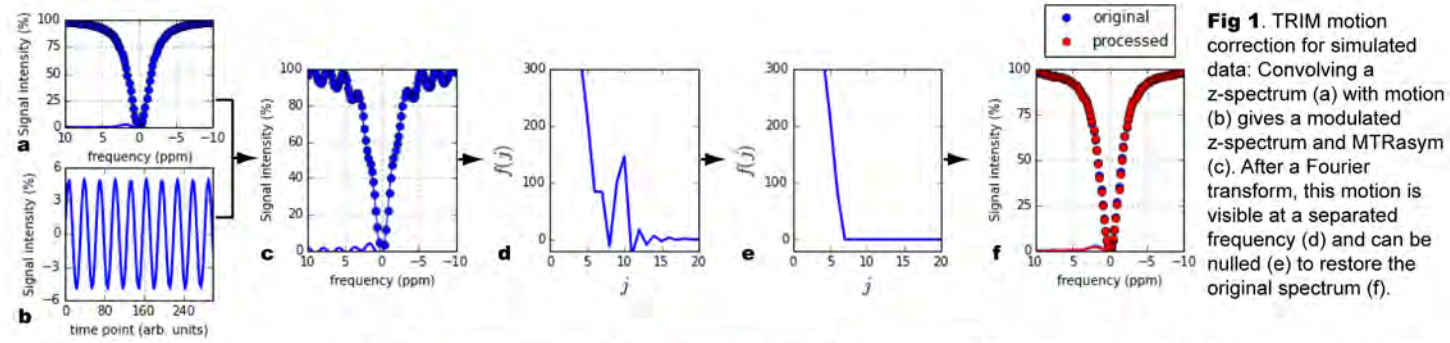

Fig 1. TRIM motion correction for simulated data: Convolving a z-spectrum (a) with motion (b) gives a modulated z-spectrum and MTRasym (c). After a Fourier transform, this motion is visible at a separated frequency (d) and can be nulled (e) to restore the original spectrum (f).

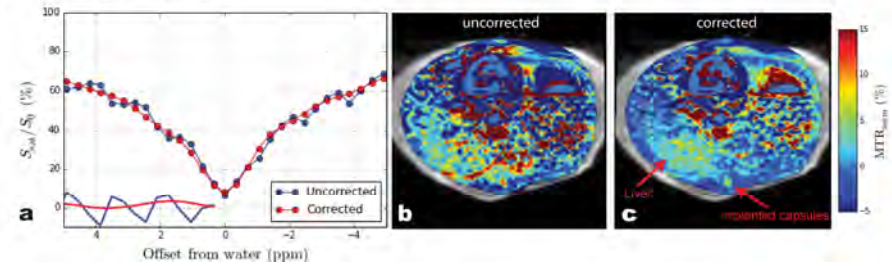

Fig 2. TRIM motion correction for experimental data from a live swine injected with arginine capsules. (a) A z-spectrum acquired from a region of interest in the swine abdomen. Uncorrected (b) and corrected (c) CEST maps displaying the signal intensity at the arginine capsule frequency.