rNOE evaluation in the presence of fat: a 7T phantom study.

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INTRODUCTION:

In breast imaging, strong lipid signals lead to pseudo CEST effects, especially for the spectral region [-2.0…-4.0] ppm, making accurate rNOE contrast evaluation completely impossible even for low fat concentrations. In the current study, Z-spectrum-based fat correction [1] was advanced by modelling partial lipid saturation to suppress pseudo-rNOE artifacts.

METHODS:

Phantom (10%w/w BSA solution, topped with peanut oil) measurements were conducted using a 7T MRI scanner (MAGNETOM, Siemens). A 2D GRE sequence (1 slice, 1.5 × 1.5 × 5 mm^3, FA = 10°, TE/TR = 2.04/4.2 ms) with steady-state presaturation (297 Gaussian-shaped pulses (t_p = 15 ms, B_1 = 0.6 and 0.9 µT, DC = 0.8), 106 offsets) was utilized for CEST acquisition. A novel pixel-wise fat-corrected Z-spectrum normalization was expressed using the following equation:

$$Z_{corr}(\Delta\omega) = \frac{\left|\vec{S}(\Delta\omega) - \vec{S}(\Delta\omega_{DS}) + \frac{\left|\vec{S}(\Delta\omega_{DS})\right| \cdot \sum_{n=1}^{7} A_n \cdot e^{i\cdot\gamma\cdot B_0\cdot(\delta\omega_n)\cdot TE} \cdot (\beta_n(\Delta\omega_{DS}) - \beta_n(\Delta\omega))}{\left|\sum_{n=1}^{7} A_n \cdot e^{i\cdot\gamma\cdot B_0\cdot(\delta\omega_n)\cdot TE} \cdot \beta_n(\Delta\omega_{DS})\right|}\right|}{\left|\vec{S}_0 - \vec{S}(\Delta\omega_{DS}) + \frac{\left|\vec{S}(\Delta\omega_{DS})\right| \cdot \sum_{n=1}^{7} A_n \cdot e^{i\cdot\gamma\cdot B_0\cdot(\delta\omega_n)\cdot TE}(\beta_n(\Delta\omega_{DS}) - 1)}{\left|\sum_{n=1}^{7} A_n \cdot e^{i\cdot\gamma\cdot B_0\cdot(\delta\omega_n)\cdot TE} \cdot \beta_n(\Delta\omega_{DS})\right|}\right|},$$

where $\vec{S}(\Delta\omega_{DS})$ – residual signal at spectral position of the water DS ($\Delta\omega_{DS}$ = 0 ppm without B_0 inhomogeneities), representing fat signal ($\vec{S}(\Delta\omega_{DS}) = \vec{F_0}$); $\beta_n(\Delta\omega) \in [0,1]$ – saturation of the individual lipid resonances. $\beta_n(\Delta\omega)$ were simulated for each of the 7 fat resonances with a pulseq-CEST for B1 in range from 0.3 to 1.2 µT with 0.005 µT step. T_1^n, T_2^n, A_n (relative amplitude), $\delta\omega_n$ (chemical shifts) of individual fat resonances were measured for each fat resonance with ^1H MRS of pure peanut oil. Fat-corrected and uncorrected $MTR_{R_{ex}}(\Delta\omega_{rNOE})$ contrasts were calculated after 4-pool Lorentzian fitting of the corresponding Z-spectra.

RESULTS:

The new normalization shows a significant reduction of the fat related artefacts (Fig.1A) in the region -2.0…-4.0 ppm of the Z-spectrum. As a result, fat-corrected $MTR_{R_{ex}}(\Delta\omega_{rNOE})$ contrast appears to be homogeneous (Fig.1B) and significantly less dependent on fat fraction (Fig.1C).

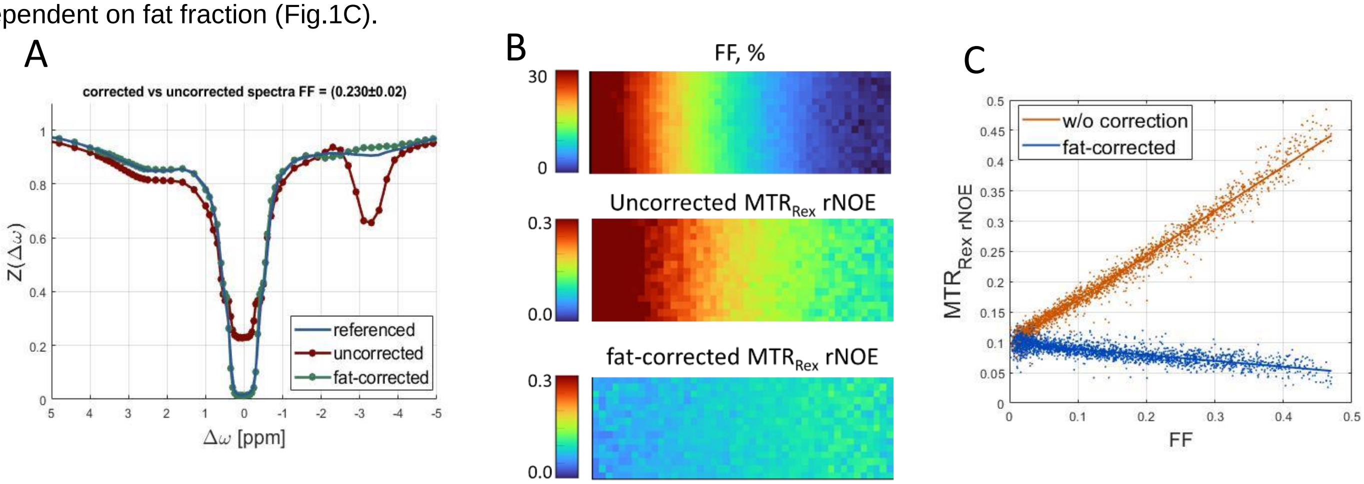

Fig1. Conventional (red) and fat signal-corrected Z-spectra (green) as compared to a reference Z-spectrum without fat contamination (blue) at B1 = 0.6 µT (A); Fat fraction (FF) map and uncorrected/fat-corrected MTR_{Rex} rNOE contrast (B); (C) Voxel-wise MTR_{Rex} values as a function of the fat fraction (FF) with (blue) and without (orange) fat correction.

DISCUSSION:

The novel normalization was shown to significantly reduce pseudo-rNOE artifacts. The proposed method relies only on the information contained in the Z-spectrum and does not require additional data acquisition (e.g. fat saturation, multiple echo times, etc.), which is the main advantage of the concept. The method does not require any additional SAR and also provides the possibility to retrospectively analyze the CEST data obtained without any fat saturation. The residual pseudo-rNOE artifacts might be associated with incomplete water saturation ($\alpha(\Delta\omega_{DS,water} \neq 0)$) and simulation imperfections. Therefore, further optimization may still be necessary for the implementation of the method into clinical practice.

CONCLUSION:

The novel normalization unlocks the potential for accurate rNOE estimation in fatty tissue, which could be a meaningful biomarker for investigations of pathologies such as breast cancer.

REFERENCES:

1. Zimmermann F *et al*. Magn Reson Med 2020;83:920-934.