Single-Shot-RARE for rapid 3D hyperpolarized metabolic ex vivo tissue imaging: RF-pulse design for semi-dense spectra

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Single-Shot-RARE for rapid 3D hyperpolarized metabolic ex vivo tissue imaging: RF-pulse design for semi-dense spectra

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Introduction

MRS of hyperpolarized (HP) 13C-enriched compounds is a promising method for in vivo cancer diagnosis[1]. Sentinel lymph node ex vivo tissue sample histology used in clinical routine for breast cancer metastasis diagnosis[2] requires time consuming sample analysis. 3D-HP-MRSI can potentially speed up the diagnosis given a sensitive marker that can be efficiently imaged in tissue after homogenous injection. The entire sample can be confined within the imaged volume giving the possibility of complete spatial non-selectivity of the radio frequency (RF) pulses in the RF pulse design with no chemical shift localization errors. Since only a few product signals are of interest for this application, a combination of under-sampled temporal encoding, frequency selective excitation and the Single-Shot-RARE-sequence offers favourable SNR characteristics. Small peak separations are challenging, however, since they require narrow excitation transition-bands. We have designed a 3D-MRSI pulse sequence for hyperpolarized ex vivo sample imaging for semi-dense compound spectra (few components, relatively small separations), ultimately aimed to be used for metastasis detection in excised lymph nodes.

Methods

3D-SS-RARE was implemented on a 4.7T pre-clinical MR-scanner (Agilent Inc., USA) with a gradient-echo train (GET) applied during spin-echo formation and with elliptical Cartesian spiral phase-encoding. Shinnar-LeRoux (SLR) excitation and refocusing RF-pulses were generated (matpulse) with parameters and nominal frequency profiles shown in Figure 1. In a spin-echo experiment the two pulses optimally give complete refocusing within the excitation pass-band and complete inversion in the adjacent excitation rejection-bands. The signal frequency response profile S(f) was measured with a single resonance thermally polarized (TP) phantom. Separation and selectivity was measured with a TP 3-model-component phantom (separation=190Hz). The signal distribution in a lymph node was measured after injection of HP compound. Coils: Volume-Tx–Loop-Rx (Rapid Biomedical GmbH, Rimpar, Germany). Polarizer: HyperSense (Oxford Instruments). Parameters: ETL(phantom)=208 ETL(lymph-node)=112, ESP=25ms, GET-length=17 and GET-ESP=0.832ms. Reconstruction: Least-squares[3].

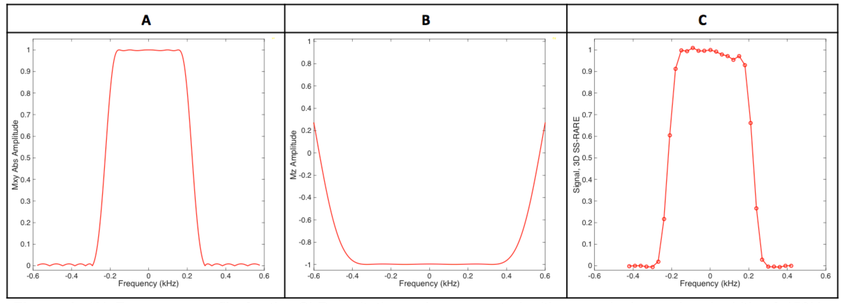

Figure 1. (A) Frequency profile for the SLR excitation pulse generated with a nominal pass-band width of 450Hz, transition-bandwidth 125Hz, pass-band ripple 0.3% and rejection-band ripple 0.8%. (B) The frequency profile for the SLR refocus/inversion pulse was chosen with a nominal pass-band width of 1050Hz, transition-bandwidth 338Hz, pass-band ripple 0.3% and rejection-band ripple 10%. (C) The signal frequency response profile measured with 3D SS-RARE on a single resonance TP phantom.

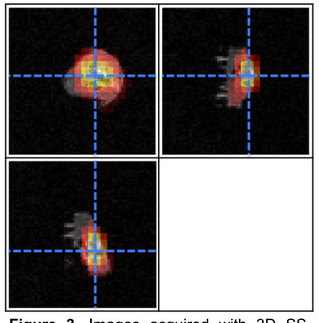

Figure 3. Images acquired with 3D SS-RARE of single resonance hyperpolarized HP001 injected into a lymph node. 13C-images are displayed as color-coded overlays on corresponding 1H-images.

Results/Discussion

The measured frequency profile S(f) of the two pulses combined in the CMPG-echo-train of the 3D SS-RARE sequence, demonstrated little pass-band ripple, desired transition bandwidth and that the nominal excitation profile is maintained throughout the echo-train (Figure 1A,C). Full exclusion of a rejection-band component from the SS-RARE spectrum (Figure 2B) and complete separation of three equally separated pass-band components (Figure 2A) was thereby demonstrated in the TP three-component phantom measurement. The differences in the point-spread-functions for C1,C2 and C3 observed in Figure 2 are caused by signal apodization differences from different transverse relaxation times of the model compounds. Figure 3 shows that the injected compound is distributed in the lymph node where SNRmax=221 for 1.5x1.5x1.5mm^3 spatial resolution.

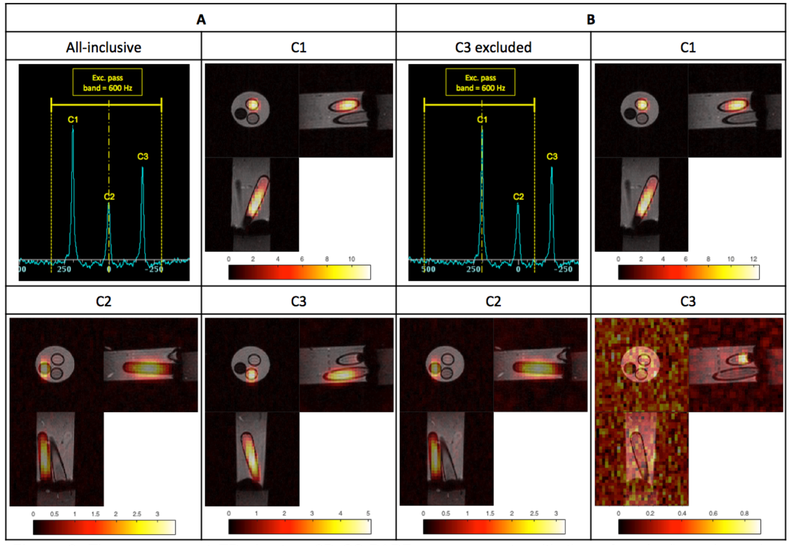

Figure 2. Three-component TP phantom 3D SS-RARE measurements with the refocusing/inversion pulse shown in Figure 1 and with nominal excitation pass-bandwidth 600Hz, transition-bandwidth 125Hz, pass-band ripple 0.3% and rejection-band ripple 0.8%. (A) Carrier frequency selected to include all three components in pass-band. (B) Carrier frequency selected to exclude the component C3 of lowest frequency. Complete exclusion of the component C3 of lowest frequency is observed (B-C3). A low signal from component C1 is observed in the metabolite map of C3 (B-C3) due to local B0 inhomogeneities. 13C-images are displayed as color-coded overlays on corresponding 1H-images.

Conclusion

A 3D SS-RARE sequence was implemented, optimized and its applicability experimentally demonstrated for metabolic imaging of hyperpolarized substances injected into ex vivo lymph node tissue samples. It shows desired spectral separation for components within the excitation pass-band by Least-squares-reconstructed under-sampled temporal encoding and exclusion of rejection-band components through SLR pulse-design for a semi-dense model spectrum. SNR was high and the spatial distribution well resolved in tissue.

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