Off-resonance behaviour of RARE and TrueFISP in imaging of hyperpolarized 13C

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Introduction: Imaging of hyperpolarized ^{13}C has recently gained interest for metabolic imaging [1]. In comparison with ^{1}H imaging, the signal of hyperpolarized substances cannot build up a steady state during an imaging sequence as it decays irreversible to the thermal equilibrium value. Therefore, TrueFISP (FIESTA, balanced SSFP, b-FFE) and single-shot RARE (TSE, FSE) show comparable signal behaviour for on-resonance signal. However, TrueFISP images of hyperpolarized substances suffer in general from off-resonance signal in contrast to RARE. We demonstrate that due to off-resonance effects TrueFISP has no advantage in comparison with RARE when hyperpolarized substances are imaged.

Methods: A ^{13}C-labeled sample of pyruvic acid was polarized with the DNP method [2]. The T_1 and the T_2 of the sample (a syringe of 1-cm diameter) were 75 s and 6 s, respectively. The sample was transported to the scanner (Siemens Sonata 1.5T) room and placed in the center of a ^{13}C rat birdcage coil. Imaging started ~1 min after polarization. The image quality of TrueFISP compared with single-shot RARE was explored with respect to flip angle α and resonance frequency offset of the sample. TrueFISP was played out with the ordinary RF-pulse train of $\alpha/2\ -\alpha\ +\alpha\ -\alpha\ \ldots$. The RF pulse train of single shot RARE was 90° 90°+$\alpha/2$ $\alpha\ \alpha\ \alpha\ \alpha$ ..., the exciting 90° pulse was played out with phase of 90° while the refocusing pulses (plus a 90°+$\alpha/2$ preparation to reach the pseudo steady state) have zero phase. Every scan was performed with the following parameters: matrix size 64*64, FOV 200*200 mm^2, TR=10.41 - 10.75 ms. K-space was centrically reordered to obtain a SNR benefit from high initial signal. Flip angle, slice thickness and scanner frequency were varied. High flip angles were examined as α=180 was evaluated in [3] to give the best SNR for hyperpolarized substances. Acquisition time for one image was about 0.7s.

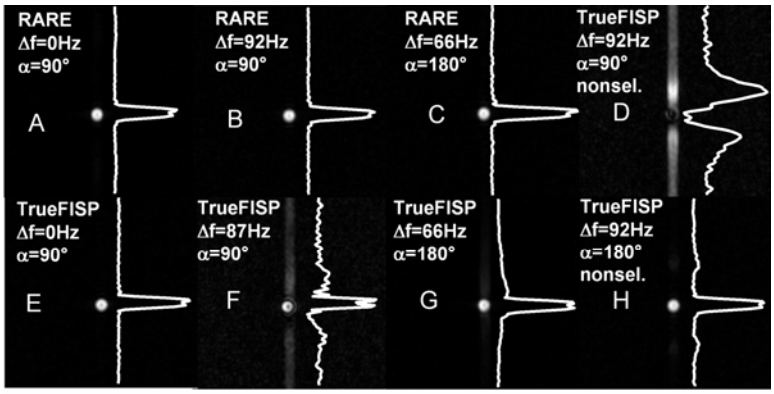

Figure 1: Comparison of single-shot RARE and TrueFISP. Artefacts are visible for TrueFISP but not for RARE in case of off-resonance excitation (Δf>0Hz). Note D and H were acquired with a nonselective pulse while all other images show slice thickness of 10 mm.

Results: Figure 1 shows images reconstructed from data acquired with either RARE or TrueFISP. The plotted profiles correspond to the intensity along the central column in phase encoding direction (top-down), which makes artefacts easier to recognize. The offset of the sample's Larmor frequency with respect to transmit frequency is indicated as Δf. Data for Fig. 1A and 1E were acquired with on-resonance excitation, RARE and TrueFISP perform equally well. All other data was acquired off-resonance, which results in artefacts along phase encoding direction for all TrueFISP experiments (D,F,G,H). RARE acquisition does not lead to artefacts in any of the images (B,C). Note that the TrueFISP images 1D and 1H were obtained from data acquired with non-selective excitation to minimize effects from non-rectangular slice-profile. In this case [3], excitation with 180° flip angle leads to decent image quality with low artefact intensity (H). This behaviour is reflected in the simulations in Fig. 2, where the TrueFISP magnitude signal without phase encoding at echo time shows severe oscillations for a flip angle α=90° but no oscillations for α=180° (simulated with T_1/T_2=25s/4s). In both cases (α=90 and α=180°), the simulation in Fig. 2 does not show signal oscillations for the RARE signal. Note that for α=180°, the simulated TrueFISP and RARE signals are identical.

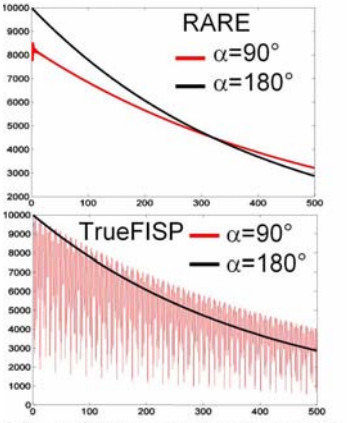

Fig. 2: Simulated signal over 500 (TR=10.75ms) sequence cycles, signal 66Hz off-resonance.

Discussion: The presented experiments show that for fast imaging of hyperpolarized substances, RARE is superior to TrueFISP as it is generically not sensitive to off-resonance artefacts. In ^{1}H gradient echo imaging, TrueFISP has the advantage of a high steady state level, whereas for hyperpolarized nuclei such a steady state is practically zero due to the irreversible decay of the hyperpolarization. In terms of motion artefacts, TrueFISP is regarded to be less sensitive than RARE, but this could not be tested in our experiments with a static phantom. Anyway, RARE can be easily equipped with flow compensating gradient if flow turns out to be a source of artefacts. Sensitivity of TrueFISP to off-resonance effects is illustrated in simulations, however, for a more detailed exploration of the TrueFISP artefact behaviour, a more elaborated simulation (preferably with direct integration of Bloch equations as high flip angles and off-resonances are targeted) is required that takes into account slice profile effects and field inhomogeneities. In the scenario of fast spectroscopic imaging as required in metabolic imaging, off-resonances are naturally present and RARE should be the imaging method of choice [4]. However, in the special case of non-selective excitation with 180° flip angle, TrueFISP is not sensitive to off-resonance effects, and has already found application for ^{13}C angiography [3].

References: [1] Golman et al., PNAS 2006, 103(30),11270-5. [2] Ardenkjaer-Larsen et al., PNAS 2003, 100(18), 10158-63. [3] Svensson et al., MRM 2003, 50(2), 256-62. [4] Månsson et al., 14th ISMRM 2006, No. 584