PHIP-Enhanced Natural Abundance ^{13}C Imaging in a Clinical MRI System via $^{1}H/^{13}C$ Polarization Transfer

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Introduction

Parahydrogen Induced Polarization (PHIP) achieves a hyperpolarized ^{1}H state by hydrogenation of a double or triple bond using parahydrogen (1,2). A commonly employed molecule for PHIP is hydroxyethyl acrylate that upon hydrogenation yields hydroxyethyl propionate (HEP) via a water-soluble catalyst. The ^{1}H hyperpolarization can be transferred to heteronuclei with lower gyromagnetic ratios, such as ^{13}C, using a modified version of the refocused INEPT sequence (PH-INEPT+, (3)) to enable ^{13}C-MRI and MRS. A further advantage is the increased lifetime of the hyperpolarized state. However, the INEPT pulse sequence requires a combination of pulses at both ^{1}H and ^{13}C frequencies, conventionally transmitted simultaneously. The aim of the current study was to realize the PH-INEPT+ sequence for HEP in a conventional clinical NMR scanner equipped with a single RF transmit channel and to use the hyperpolarized ^{13}C state of HEP at natural abundance to perform MRI.

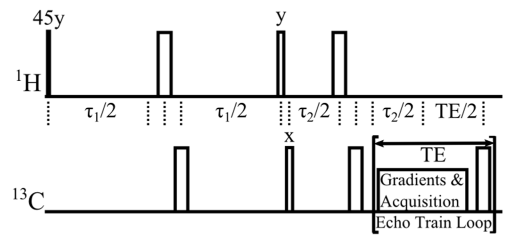

Fig. 1. Sequential PH-INEPT+ polarization transfer sequence combined with a RARE echo train for imaging.

Materials and Methods

Measurements were performed on a clinical 1.5 T NMR scanner (Magnetom Sonata, Siemens) combined with an in-house manufactured double resonant $^{1}H/^{13}C$ coil optimized for 10 mm NMR tubes. 500 mg of the precursor molecule hydroxylethyl acrylate without isotope enhancement, 10 mg catalyst and 2.6 g D_2O were filled into an NMR pressure tube. The samples were heated to 70°C, pressurized with 4 bar of 93% enriched parahydrogen and vigorously shaken inside the bore of the NMR scanner for 5 s. Since the NMR scanner is only equipped with a single RF transmit channel, a sequential version of the PH-INEPT+ sequence was implemented for a single $^{1}H/^{13}C$ polarization transfer (Fig. 1), analog to the sequential refocused INEPT sequence of Klomp et al. (4). The delays of the sequence were set to τ_1: 27.7 ms and τ_2: 14 ms, yielding the same phase of the $^{13}C_1$ and $^{13}C_2$ peak of HEP(5). The first echo refocusing after the PH-INEPT+ sequence was used for the center k-space line followed by a RARE echo train combined with a centric reordering scheme (TR/TE: 120/15 ms, FOV: 25x25 mm, 8x8 pixel). The echo train was repeated to acquire 64 sequential images.

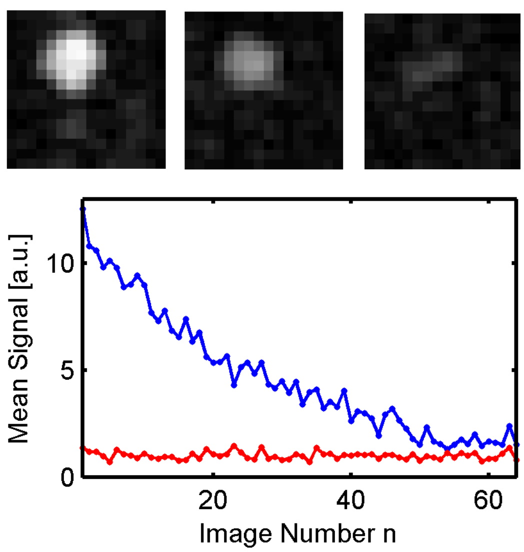

Fig. 2. Mean Signal inside the NMR tube (blue) and in a noise region (red). On top the images number 1, 16 and 45 are shown.

Results

In Figure 2 the mean signal inside the NMR tube as function of the image number is shown. As expected the signal shows an exponential decay. The first acquisition yields an SNR of 13. By cumulative averaging in the echo train, the SNR could be increased up to 40. The corresponding image is shown in Figure 3.

Discussion

The sequential PH-INEPT+ sequence can be used to transfer the proton hyperpolarization to carbon-13 inside the NMR scanner. The RARE sequence shows a good feasibility to achieve the maximum SNR from a given amount of hyperpolarization. Further analysis should be performed to optimize imaging parameters like TE.

Conclusion

Polarization transfer from PHIP hyperpolarized protons to carbon-13 was realized inside an NMR scanner using sequential RF transmission with a double resonant $^{1}H/^{13}C$ coil. The hyperpolarized natural abundance ^{13}C was used to acquire images with an SNR up to 40, illustrating that .the RARE sequence allows for an efficient usage of the hyperpolarization.

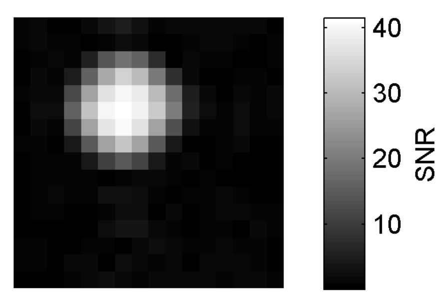

Fig. 3. ^{13}C image averaged in the echo train over the first 18 images.

References

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