First MRI of Micro-Fluid Jets with In-bore DNP of 1H at 1.5 T

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Motivation

Dynamic Nuclear Polarization (DNP) is a technique to achieve hyperpolarization of MRI agents by microwave irradiation of electron spins in radicals, which are coupled to the imaged nuclear spins. Due to significant difference of electron and nuclear magnetic moments the NMR signal enhancement **by two orders of magnitude** is possible. Typically, the DNP is performed in an external polarizer, in the solid-state at low temperatures, with subsequent melting and transferring of the imaging agent into MR-scanner. Being optimal for signal enhancements, the requirement to shuttle the sample practically prohibits the use nuclei with short T_1 relaxation times, like ^{1}H. To circumvent these we use **liquid-state** "Overhauser DNP" at 1.5 T for ^{1}H nuclei that allows placing the polarizer core inside MRI magnet very close to the imaging objects and delivery of hyperpolarized (HP-) agent **in continuous flow mode**.

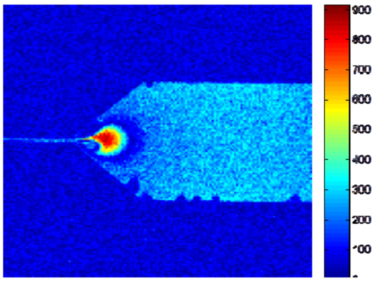

Fig 1a : Single shot SGRE image at 30ml/h flow. Sequence parameters: TR/TE=100/10ms Voxel size= 0.1x0.1x0.4mm. One can clearly observe the jet of hyperpolarized, thus hyper-intense sample into the cell filled with thermally polarized sample.

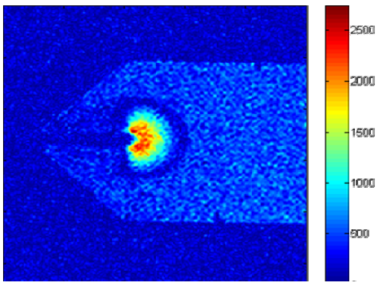

Fig 1b: Single shot Spin Echo image at the same flow rate. Sequence parameters: TR/TE=500/15ms Voxel size= 0.1x0.1x0.4mm.
HP sample inside the inlet capillary moves rapidly and therefore the signal is eliminated by spin-echo due to the de-phasing effect which is typically stronger than for GRE sequence.

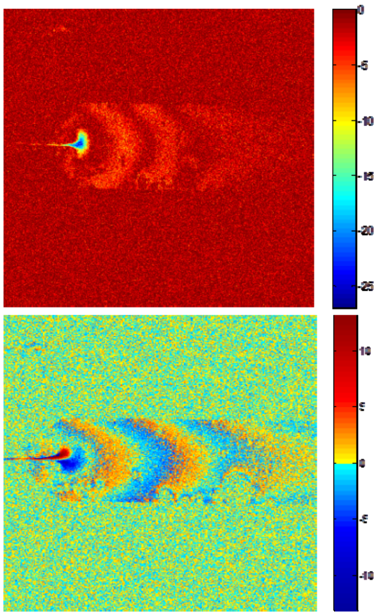

Fig 2 Real (top) and imaginary (bottom) part reconstruction of GRE image at 20 ml/h flow rate. Signal is normalized to the noise standard deviation calculated from 2 signal-free ROIs. One the real part one could see that DNP provide a negative enhancement relative to the thermal polarization. The laminar flow zone in the cell (parabolic profile of phase variation) and jet-flow zone near capillary inlet can be clearly distinguished.

Materials and methods

The microwave source for DNP was a frequency synthesizer tunable from 40 to 45 GHz. The microwaves are transferred to the copper resonator (hollow-bore cylinder, ID=11 mm) inside scanner magnet by the wave-guide. The hyperpolarized agent in resonator streams through the ID=0.3mm pipe. The resonator outlet capillary has ID=0.15 mm. The 0.4 mm Plexiglas flat-cell is used as a phantom. The 2D-cell excludes partial volume effect and allows estimation the DNP signal enhancement with intrinsic reference of thermally polarized sample. The ^{1}H MR-images were acquired by 1.5T MR-Scanner Magnetom Sonata, (Siemens, Erlangen, Germany) using 20mm pick-up loop coil. Sample (20mmol TEMPOL solution) was streamed with flow rate of 10-30 ml/hours. Spin-Echo and Spoiled Gradient Echo (SGRE) sequences have been used to visualize the inflow of hyperpolarized agent into the cell. The repetition time (TR), flip angle (FA) and flow rate were varied to check their influence on the resulted images intensity and quality. The comprehensive numeric simulation of the effect of whole set of image acquisition parameters on image SNR and resolution is in progress.

Results and Conclusion

Fig 1 (a,b) shows the jet of HP-sample from the outlet capillary of resonator into the flat cell filled with sample at thermal polarization acquired with GRE and SE sequences respectively. While traveling through the cell the HP-sample creates a steady-state signal intensity distribution. Because of the negative enhancement of the NMR signal by DNP, it passes through zero intensity, creating a dark region before it reaches thermal polarization. Fig 2 shows the real and imaginary part of the SGRE image in SNR units. The "far-zone" with laminar flow in the cell could be clearly distinguished by phase variation with parabolic-like profile. The hyperpolarized sample provides the SNR gain by the factor 12 in the zone near inlet capillary. The abrupt phase variation reflects the jet-type flow character development that could be visualized with in-plane 0.1mm^2 in-plane resolution. These results demonstrate the ability to create a continuous flow of a hyperpolarized liquid sample directly in the 1.5 T field and to obtain MRI of micro-fluid jets in real time. The technique and setup are equally applicable for hyperpolarization of X-nuclei (^{13}C, ^{31}P, ^{19}F) either by "Overhauser contact" with the solution of radicals or by polarization transfer using nuclear Overhauser effect. The potential in-vivo applications would require increasing the polarizer performance and immobilization (at least partially) of free radicals before injection the HP-agent to the animal. The limiting factor of the setup is the amount of HP-sample produced (few μl/s) A manifest improvement step would be to enlarge the resonator cavity and sample flow speed. However, maintaining of HP buildup time would require larger microwave power.

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