High Speed 3D Overhauser-Enhanced MRI using combined b-SSFP and Compressed Sensing

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Target Audience: Free radical imaging, hyper-polarization, MR method development and hardware

Purpose

Free radical imaging has been used to investigate physiological processes such as pO_2 mapping and to monitor the distribution and metabolism of free radicals in organs under oxidative stress. We present a new pulse sequence for rapid 3D imaging of free radicals using Overhauser-enhanced MRI (OMRI). In contrast to other OMRI methods that use a time consuming pre-polarization Overhauser irradiation step, the sequence presented here embeds the EPR pulses into the phase encode step of a balanced steady state free precession sequence (b-SSFP), greatly reducing the acquisition time. A further increase in temporal resolution is gained by undersampling of k-space and using compressed sensing reconstruction. This new OMRI sequence enables both improved spatial and temporal resolution of free radical distribution than other techniques.

Methods

Experiments were performed in a custom built, 6.5 mT, bi-planar electromagnet with bi-planar gradients. A 7 cm OD, 13 cm long Alderman-Grant coil was used to saturate the 140.8 MHz electron spin resonance of the nitroxide radical 4-hydroxy-TEMPO. The EPR coil was placed inside a 10 cm OD, 16 cm long solenoid coil for ^{1}H NMR excitation and detection. The EPR irradiation pulses were embedded into the phase encode and rewind steps of a fully balanced SSFP sequence as shown in Figure 1. 3D printed polycarbonate pieces 5.4 cm in diameter were used as a phantom (Figure 2a) with 2.5 mM TEMPO solution in water. Pieces were designed to evaluate the ability to resolve small feature in 3 dimensions. Image parameters were: matrix = 256x64x32, voxel size = 1x1x3.5mm, TR/TE = 54/27 ms, α = 90^o, 70% undersampling rate, acquisition time = 65 s.

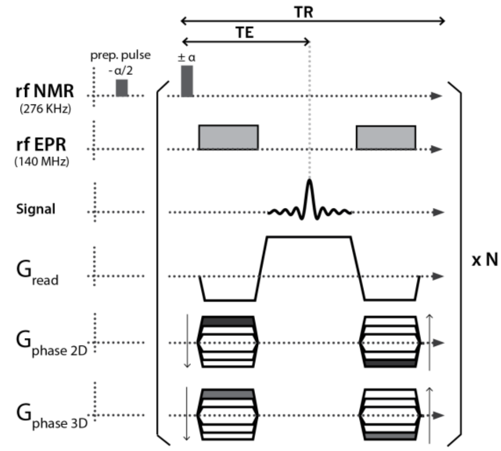

Figure 1. The 3D b-SSFP sequence with embedded EPR pulses.

Results

Figure 2a) shows two segments of our phantom with the corresponding images in Figure 2b). The under-sampled data accurately reproduces the object, including the 1 mm diameter holes and 1 mm spacer. To confirm that this new sequence with imbedded EPR pulses is still a steady-state sequence, the sequence was run with only the read gradient while the echo amplitude was measured. After an initial buildup of polarization due to T_1, the signal reaches a steady-state amplitude that is ~ 30X larger than without embedded EPR pulses.

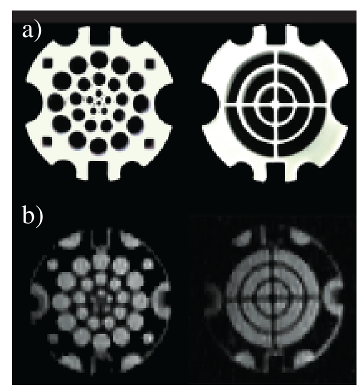

Figure 2. 2 slices from an OMRI image at 6.5 mT with 1x1x3.5 mm resolution over a 200 cm^3 sample in 65 s. Phantom is 5.4 cm in diameter.

Conclusion

Embedding electron spin saturation into the phase encode step allows the use of a traditional b-SSFP sequence with no additional timings added. This is the first source of acceleration compared to traditional OMRI sequences that have a pre-polarization step of order T_1 before acquiring several lines of k-space. Further, for the phantom imaged here, only 30% of k-space is was necessary to faithfully reproduce the image, reducing the acquisition time by a factor of 3. This technique will improve our ability to monitor physiological processes involving free radicals as the distribution of radicals can be tracked with greater spatial and temporal resolution. **Acknowledgement:** Funded by DoD, Defense Medical Research and Development Program, Applied and Advanced Technology Development Award W81XWH-11-2-0076 (DM09094).