Radial Single-Shot STEAM MRI

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The objective of this work was to develop a radial single-shot STEAM MRI sequence which combines the advantages of the stimulated echo signal with the radial encoding scheme. First promising experimental results are presented for phantom data as well as for in vivo measurements.

Theory: Single-shot STEAM MRI is a high-speed imaging technique that uses a train of stimulated echoes from only one magnetization preparation to obtain all raw data for a single slice (1). A major advantage of this method is that all echoes acquired are RF refocused and, thus, the sequence is insensitive to artifacts from off-resonance effects including tissue susceptibility differences. It has been shown that this property can be exploited to perform reliable diffusion tensor imaging in brain areas with significant off-resonance contributions caused from neighboring air-tissue interfaces (2). Such brain areas are hardly accessible using conventional EPI sequences due to heavy distortion artifacts. However, as half of the magnetization is lost during the magnetization preparation of the STEAM sequence only a reduced amount of magnetization is available for the data acquisition. The lower signal-to-noise ratio is a major limitation of the STEAM technique and, hence, EPI sequences are used more frequently for diffusion tensor imaging.

On the other hand, radial sampling strategies are currently gaining strong interest due to unique beneficial properties that include a low sensitivity to motion and the ability to extract object information from undersampled data. However, the practical use of radial trajectories is hampered by a more complex image reconstruction and a severe sensitivity to off-resonance effects which precludes the utilization of gradient echoes in many situations.

Very recently, we developed an iterative multi-coil reconstruction approach that enables recovering the object from very limited radially acquired data without or, at least, strongly reduced undersampling artifacts (3). Therefore, we combined the advantages of the STEAM technique with the benefits of radial encoding by adopting the single-shot STEAM sequence to the radial sampling scheme. In fact, single-shot STEAM and radial encoding complement one another very well: While the use of the RF refocused STEAM signal eliminates the off-resonance sensitivity of the radial trajectory, the undersampling ability of the radial sampling scheme compensates for the limited magnetization available in the STEAM technique.

Methods: All experiments were conducted using a Siemens Tim Trio system at 2.9 T with a 12-channel head coil in triple mode. A readout oversampling factor of two was used and an isotropic gradient delay correction was applied. Optimized RF pulse waveforms were calculated to obtain improved slice profiles. Variable flip angles were used in the train of alpha pulses to account for the subsequently lowered magnetization. Because the flip angle variation only approximately compensates for the decay and, further, there is T1 relaxation, the amplitude of successively sampled spokes decreases. Therefore, a spoke reordering scheme was implemented that distributes the lower signal equally in k-space and avoids sharp amplitude differences between neighboring spokes. A field-of-view diameter of 230 mm was chosen for the phantom and 210 mm for the in vivo study (bandwidth 180 Hz/pixel, 2 mm slice thickness).

All images were reconstructed using the mentioned iterative approach which is based on non-linear optimization and employs a total variation constraint to prevent streaking artifacts from undersampling. A spoke intensity correction was incorporated relying on the assumption that the sum of the object's projection profile should be independent of the angle. Hence, the sum of the projection profiles calculated from the measured spokes can be used for a first order compensation of remaining spoke intensity fluctuations, in particular due to T1 relaxation.

Results: Fig.1 shows reconstructions of phantom and human-brain data from 48 spokes with a base resolution of 128, 192 and 256 pixels. It can be seen that the proposed method is able to resolve the objects with a very high resolution for a single-shot technique. The increase of the base resolution from 128 to 256 pixels is accompanied by an obvious loss of signal-to-noise ratio due to the lower bandwidth and higher factor of undersampling. Fig. 2 shows respective reconstructions from 24, 32 and 48 spokes with a fixed base resolution of 192 pixels. The reduction of measured spokes leads to some degree of resolution degradation and an incomplete removal of undersampling artifacts in the case of 24 spokes. However, it is astonishing how well the objects can be recovered from such low number of spokes.

All reconstructions shown are affected by slight noise patterns surrounding the objects. We believe that these artifacts originate from insufficiently accounting for the actual signal evolution during the readout intervals. Therefore, a next step will be to extend the image reconstruction approach by an improved modeling of the received signal that includes decay processes.

Conclusion: This work presents a new method for high-speed imaging based on a beneficial combination of the STEAM MRI technique with the radial encoding scheme. On the one hand, the RF refocused signal enables to utilize radial k-space sampling in a single-shot scenario and, on the other hand, the radial undersampling capability allows making optimal use of the limited magnetization available. Furthermore, the flexibility to choose the number of spokes independently from the base resolution enhances the options to design protocols for specific imaging needs.

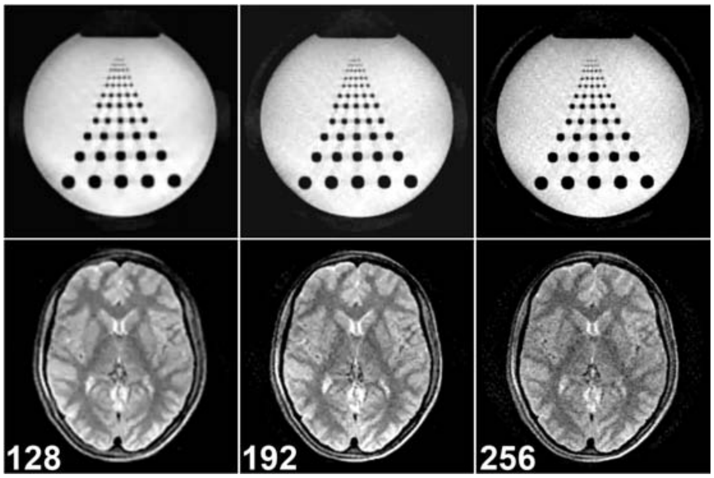

Fig. 1: Reconstructions of phantom (top) and in vivo data (bottom) from 48 spokes with a base resolution of 128, 192 and 256 pixels.

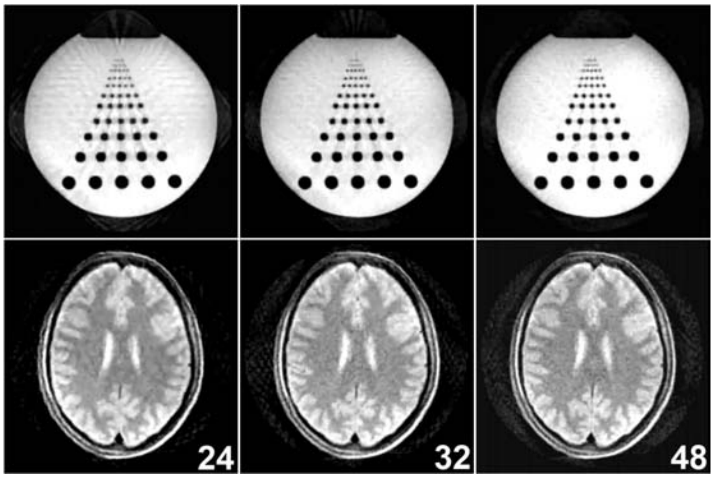

Fig. 2: Reconstructions of phantom (top) and in vivo data (bottom) from 24, 32 and 48 spokes with a base resolution of 192 pixels.

References
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