An Optimized 3D Interleaved Cylindrical Pulse Sequence with Reduced Oversampling

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Introduction

An interleaved 3D cylindrical k-space trajectory (1) may offer significant benefits as an efficient and highly flexible sampling scheme. The trajectory is also very robust due to a constant gradient along the slab-encoding direction, which results in shifted, instead of blurred, off-resonance signal intensities. However, previous implementations as a general-purpose 3D gradient-recalled echo (GRE) pulse sequence used a constant number of interleaves for each of the concentric cylinders, independent of its radius (2). The consequence was substantial oversampling in the central k-space regions. While the maximum cylinder radius is dictated by the maximum gradient amplitude and slew rate of the gradient subsystem this is not true for the inner cylinders, which opens the door to a reduction in the number of interleaves while increasing the gradient slew rate and amplitude towards the center of k-space. In this study we drastically reduced the oversampling to optimize the sequence for speed and achieved a 35% decrease in acquisition time.

Methods

All experiments were performed on a 1.5T commercial whole-body imager (Sonata, Siemens Medical Solutions, Malvern, PA). The speed-optimized and non-optimized 3D cylindrical trajectories share largely the same parameters except for the number of interleaves and, consequently, the number of revolutions per interleave. The trajectory consisted of 128 concentric cylinders [2,3] where each cylinder was formed by 16 interleaved 4-turn helices along which 1024 data points per interleave were sampled. The data were gridded onto a subsampled 128×128×128 matrix and Fourier transformed. For the speed-optimized version the number of interleaves varied from 1 at the k-space origin to 16 at the k-space edge. The number of interleaves for a given cylinder, N_{opt}, were calculated as

$$N_{opt} = N_{max}\sqrt{R / R_{Total}}\ ,$$

where N_{max} is the maximum number of interleaves, R the current ring number and R_{Total} the total number of rings. Adhering to this equation ensures that the slew rate used for the cylinder with the largest diameter is never exceeded by the smaller cylinders.

The cylinders were acquired from the outside in to prevent artifacts due to signal fluctuations during the approach to steady state. Other imaging parameters were: flip angle 10°, TR/TE 25/11ms, 2.3mm isotropic resolution, 128×128×128 image matrix. We imaged a sphere phantom to obtain signal-to-noise (SNR) information as well as the head of a healthy volunteer after obtaining informed written consent.

Results

Figure 1 compares head images acquired with the non-optimized 3D interleaved cylindrical GRE sequence (51s acquisition time) to those acquired with the speed-optimized one (33s acquisition time). At first glance, the images appear almost identical with respect to contrast and overall image quality. However, the background artifacts are somewhat higher for the speed-optimized sequence. Otherwise, the images are mostly artifact free and do not require fat saturation or off-resonance correction.

In a spherical water phantom we found an SNR of 179 for the non-optimized sequence versus 122 for the speed-optimized sequence. The later SNR is less than would be expected from the 35% reduction in the number of interleaves. It is most likely due to the increased artifact level, which elevates the background noise.

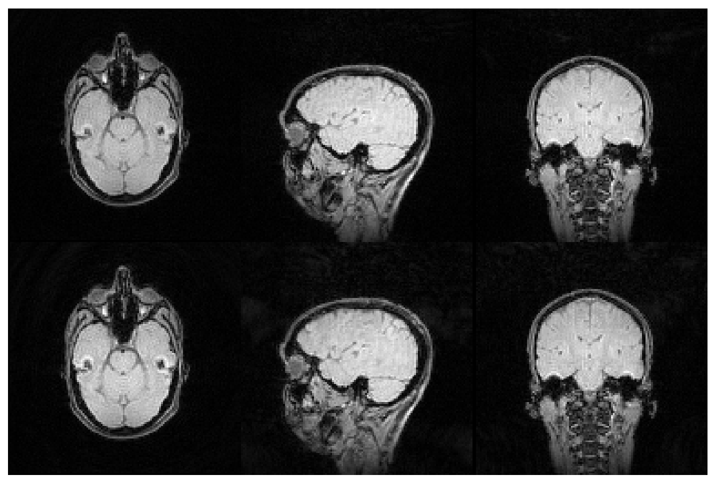

Figure 1: Image quality comparison between non-optimized (top row) and speed-optimized (bottom row) 3D interleaved cylindrical pulse sequences. Despite the 30% difference in acquisition time the images are of very comparable quality. The main difference is a slight elevation in the background artifact intensity for the speed-optimized sequence.

Discussion

A reduction in oversampling of the central k-space regions by decreasing the number of interleaves appears to be an effective tool to reduce the acquisition time for 3D interleaved cylindrical GRE sequence by about 35%. The resulting increase in background artifact level does not severely impact the overall image quality and is possibly due to sampling inhomogeneities caused by the enforced rounding of the gradients to the manufacturer-specific gradient raster time. A solution to this problem is the focus of future research.

The high efficiency of a 3D cylindrical GRE pulse sequence coupled with its excellent off-resonance behavior makes it a promising candidate for rapid 3D acquisitions. In a fully optimized implementation this sequence may be particularly useful for contrast-enhanced MR angiography and dynamic contrast MRI studies of breast and other organs.

References

[1] Wong EC. 2nd SMR; 1994, 25.
[2] Ruppert K, Oshio K, Guenther M, Mugler JP. 10th ISMRM; 2002, 208.

Acknowledgements

This work was supported by NIH grant 1R44RR16397-02A1.