

Multiple Echo 3D Hybrid Radial SSFP: Initial Applications in a Single Breath-hold Cardiac Imaging

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INTRODUCTION

While 3D radial trajectories have proved effective in imaging the entire chest or torso, hybrid acquisitions which encode the in-plane k -space dimension radially and use Fourier encoding for the slice dimension have proven useful in coronary [1], functional cardiac [2], and peripheral vasculature imaging [3]. Hybrid acquisitions are particularly useful when the FOV can be limited in a dimension for which lower resolution is acceptable. We present a SSFP hybrid radial acquisition that improves data acquisition efficiency by also acquiring radial lines during the frequency dephaser and rephaser gradient pulses, and during all readout gradient ramps. In an initial application, the sequence is used to increase temporal resolution in a cardiac function exam and suppress unwanted lipid signal.

MATERIALS AND METHODS

The hybrid 3D acquisition method uses slab selection and slice encoding along the k_z direction, with radial projections filling in the k_x - k_y plane. Unlike conventional radial sequences which acquire a diameter of k -space from a full k -space echo each TR, we collect two additional radial lines during the frequency dephaser and rephaser gradients. Efficiency is increased by also sampling along gradient ramps [4], shown in Fig. 1. Similar to the SPIDER method [1], the varying phase shifts at the different echo times cause some destructive interference for fat signal. With only an 11% increase in TR (4.2 ms vs. 3.8 ms), the amount of acquired data is doubled. A set of four radial lines per TR, illustrated in Fig. 1, are repeatedly acquired with different slice encodings to acquire a blade in k -space as shown in Fig. 2 [2]. Within each R-R interval, a number of blades are interleaved as in the top row of Fig. 2. The number of blades that can fit within the shortest anticipated R-R interval are acquired. The sequence then disables acquisition until an R wave is detected and a new set of blades at unique and interleaved angles is uninitiated. Excitations continue during disabled data acquisition to maintain the steady-state. This process is repeated for multiple heartbeats, shown in the subsequent rows of Fig. 2.

Each heartbeat may be broken down into multiple cardiac phases for which interleaved projections throughout the k_x - k_y plane have been sampled. The data for each cardiac phase may be reconstructed to produce time-resolved images. The best temporal resolution results when the time interval for each blade is treated as a separate cardiac phase, the duration of which is the TR times the number of slice encodes, as is depicted in Fig. 2. The variable density k_x - k_y sampling can also be temporally filtered, where the temporal window widens for the higher spatial frequencies which are sampled less often to improve SNR and CNR. In our work, an iterative method was used to compute this temporal filter [5].

The hybrid SSFP gradient-echo sequence was implemented on a GE TwinSpeed 1.5T scanner (GE Healthcare, Milwaukee, WI) using an eight-channel cardiac coil. An axial slab consisting of 12-16 slices of 8-10 mm thickness was excited with the following scan parameters: 26-30 cm FOV, 256 readout resolution, 45° flip angle, ± 125 kHz receiver BW, and a 4.2 ms TR.

RESULTS AND DISCUSSION

The ability of the sequence to limit the hyper-intense SSFP lipid signal is demonstrated in Fig. 3 where the normally bright subcutaneous fat signal is similar in intensity to muscle. The results in Fig. 4 were obtained on a volunteer with a rapid heart rate of 85 bpm in a 28 s scan (40 heartbeats). 12 slices were imaged with 12 cardiac phases for a temporal resolution of $12 \times TR = 50.4$ ms. With 40 heartbeats and 4 radial lines per TR, 160 radial lines were imaged per cardiac phase. With a Nyquist rate of 800 radial lines for complete sampling (≈ 256 readout points), each phase had an undersampling rate of 5. Improved image quality is likely if k -space location errors due to anisotropic gradient delays and eddy currents are corrected before combining the multiple echoes [6]. More standardized long and short axis oblique imaging will be possible after tuning is added to remove for off-axis phase demodulation errors. Longer echo trains acquiring 6 or 8 radial lines per TR may also be possible.

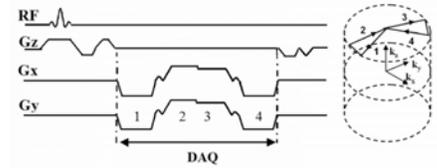


Fig. 1. Gradient echo pulse sequence collects 4 radial lines per TR in the k_x - k_y plane and slice encoding in the k_z -direction.

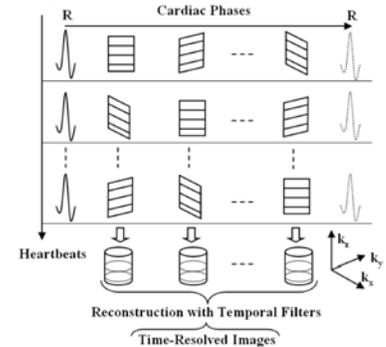


Fig. 2. Interleaved hybrid k -space acquisition scheme. Multiple heartbeats are aligned vertically, and cardiac phases progress horizontally.

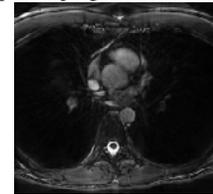


Fig. 3 Normally hyperintense SSFP lipid signal is partially suppressed through destructive interference of lipid signal at multiple echoes. .

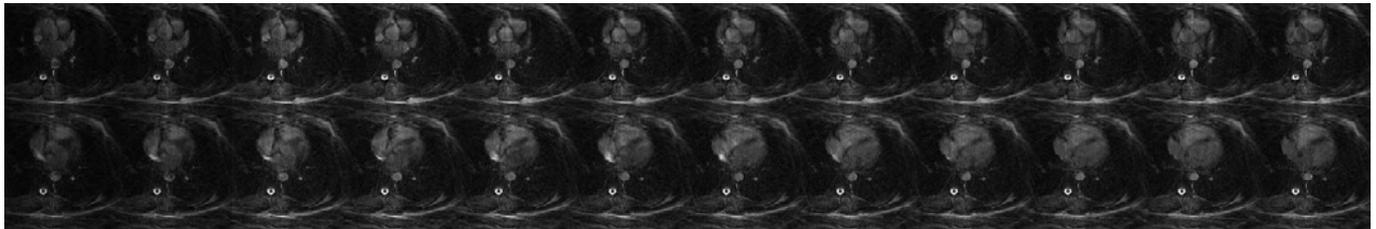


Figure 4 Two rows of axial slices depict 12 cardiac phases with a temporal resolution 50 ms. Total scan time was 28 s, FOV=26 cm, spatial resolution is $1.0 \times 1.0 \times 10$ mm

CONCLUSIONS

Improvements in temporal resolution and reduced undersampling are possible through efficient use of gradient pulses to acquire data during normally unused time periods. Though demonstrated for cardiac functional imaging, the method could apply to several dynamic imaging applications.

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