Hybrid Radial-Parallel 3D Imaging

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Introduction

Radial k-space trajectories have been shown to have certain advantages over Cartesian trajectories, such as reduced motion artifacts and the ability to increase temporal resolution through angular undersampling at the expense of increased artifact rather than decreased spatial resolution. Angularly undersampled radial imaging is well-suited for applications requiring high undersampling factors, such as time-resolved contrast-enhanced angiography (CE-MRA), because the undersampling artifacts are tolerable to a certain degree (1). Other undersampling methods include partial Fourier, parallel imaging, TRICKS (2), and UNFOLD (3), and often several of these methods are combined to achieve sufficient acceleration. Combining radial and parallel imaging in the same plane, however, presents a technical challenge since reconstruction time can be prohibitively long. Several investigators have proposed approximations to the SENSE and GRAPPA algorithms for radial data (4-6). In the case of 3D radial imaging, sampling may occur on either a cylindrical or spherical grid, the latter also called VIPR at high undersampling factors (7). For cylindrical sampling, parallel imaging may be applied through-plane without a significant increase in computational complexity. **Figure 1** is a diagram of this acquisition in k-space, where gray disks represent acquired radial lines for a certain k_z phase encode, and white disks represent lines estimated with the GRAPPA algorithm. All lines are acquired at low k_z values for both calibration and generation of low frequency coil sensitivity maps. We have implemented such a novel hybrid radial-parallel 3D imaging technique, and applied it to time-resolved contrast-enhanced MR angiography of the intracranial vasculature, where very high acceleration factors are necessary due to the ~3 s arteriovenous transit time. Partial Fourier and TRICKS techniques were then added to attain very high acceleration factors.

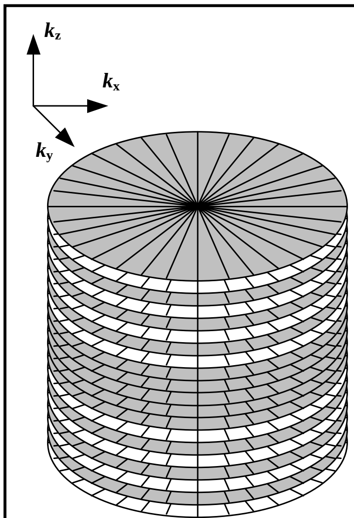

Figure 1

Materials and Methods

Images were acquired from healthy volunteers on a 1.5 T whole body MR scanner (Avanto, Siemens Medical Solutions, Erlangen, Germany) with a 4-channel head coil (Siemens Medical Solutions, Erlangen, Germany). A sagittal 3D multi-phase FLASH pulse sequence was used with an in-plane angularly undersampled radial k-space trajectory, centric reordering, and through-plane GRAPPA (FOV = 250 × 250 × 75 mm, image matrix = 256 × 256 × 30, spatial resolution = 1.0 × 1.0 × 2.5 mm, phases = 15, temporal resolution = 3.0 s/frame, TR/TE = 2.4/0.9 ms, flip = 25º, bandwidth = 980 Hz/pixel, 50% views-to-readout points ratio, GRAPPA acceleration factor/reference lines = 2/8). Partial Fourier and TRICKS were later added for greater acceleration (R-L/A-P partial Fourier factors = 0.75/0.75, 3 TRICKS segments). The scan covered either the left or right half of the head, including the sagittal sinus. A single dose of a gadolinium-based contrast agent (Magnevist, Berlex, Wayne, New Jersey) was administered in an antecubital vein at an injection rate of 5.0 ml/s, starting simultaneously with the imaging protocol. Raw data was processed online with the GRAPPA algorithm prior to regridding with a 3-sample Kaiser-Bessel window.

Results

Figure 2 displays a time series of representative sagittal subtracted MIP images of the radial imaging technique at a temporal resolution of 3.0 s. Only minor streak artifacts emanate from the sagittal sinus during venous enhancement. The technique is able to consistently capture a peak arterial phase due to the high temporal resolution.

Discussion

In applications where very high acceleration factors are necessary, splitting the acceleration amongst several techniques, each with modest acceleration, ensures that no one type of image degradation will become too severe. We have presented a novel technique in which four different types of undersampling are present: angularly undersampled radial imaging, parallel imaging, partial Fourier, and TRICKS. The first three undersample spatially, and the last one temporally. Although spherical sampling is able to achieve very high undersampling factors, the technique is limited to spherical FOV's, which may demand more coverage than necessary. Cylindrical sampling is better able to fit anatomic regions with different in-plane and through-plane dimensions. Additionally, low through-plane spatial resolution from thick partitions or partial Fourier is acceptable. Spherical sampling demands isotropic resolution. In order to accelerate cylindrical acquisition in the through-plane dimension, then, parallel imaging can be employed. In the case of high temporal resolution intracranial CE-MRA, this hybrid radial-parallel 3D imaging technique provides a noninvasive, 3D alternative to x-ray digital subtraction angiography, which may be useful for the study of arteriovenous malformations and fistulae.

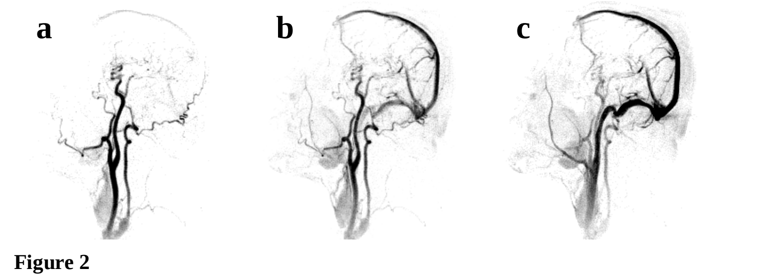

Figure 2

References

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