High-quality clinical MRI massively accelerated with segmented echo-planar readout and phase-cycled reconstruction

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Introduction

Every year millions of patients (e.g., children, seriously ill patients and claustrophobic individuals) cannot complete lengthy MRI procedures without sedation or anesthesia, which poses significant risks for serious adverse effects and harm to health, such as oxygen desaturation, respiratory distress, cardiac arrest, injury to arteries, veins or nerves, change in mood or emotions, and post-anesthetic delirium among many others. It is thus highly desirable to design a novel approach to enable millions of challenging patients to complete clinical MRI procedures that can eliminate or significantly reduce the risk of adverse effects associated with sedation / anesthesia.

Here we demonstrate that many clinical MRI sequences can be massively accelerated by 8- to 32-fold using segmented echo-planar readout, and high-quality images can be reliably obtained after removing the echo-planar related phase errors using a novel phase-cycled reconstruction algorithm [1]. Using our acquisition and reconstruction scheme, it is feasible to shorten a 40-min conventional MRI protocol to only 5 min without noticeable changes of image quality.

Methods

Many conventional spin-warp clinical MRI sequences (e.g., PD-T2 dual spin-echo, FLAIR, and susceptibility-weighted imaging among others) have significant un-used time periods. For example, Figure 1a and 1b show that the un-used period (e.g., the time between the 180-degree pulse and the data acquisition) is long and thus the scan efficiency is less than optimal for a multi-slice 2D FLAIR sequence. The FLAIR scan time can be significantly reduced (e.g., by 8-fold in Figure 1c) by acquiring multiple ky lines after each RF pulse excitation, using a segmented echo-planar readout waveform (Figure 1c).

A major concern with the segmented EPI accelerated spin-warp imaging is that the produced images are susceptible to echo-planar related artifacts, particularly the Nyquist artifact. To address this issue, we use a novel phase-cycled reconstruction algorithm [1] to effectively remove Nyquist artifacts in post-processing, without requiring any reference scan. Note that the geometric distortions are usually ignorable in segmented EPI with a short echo train length (e.g., ETL < 16).

Using this approach, we have developed a series of massively accelerated 2D and 3D clinical MRI protocols providing different contrasts (e.g., PD, T2, T1, IR, and T2*). Data were acquired from healthy volunteers at our 3 Tesla MRI scanners. The Nyquist artifacts in segmented EPI-accelerated spin-warp imaging were removed in post-processing using phase-cycled reconstruction [1]. To assess the dependence of image quality on EPI echo train length (which is linearly proportional to the acceleration factor), MRI data corresponding to different numbers of echo train lengths (1, 2, 4, 8, 16, 32) were obtained and compared.

Results

The first image in Figure 2a is a conventional T2-weighted spin-echo MRI of matrix size 256 x 256 obtained in 640 sec (with TR = 2.5 sec; TE = 100 msec). The other three images in Figure 2a are segmented EPI-accelerated T2-weighted spin-echo MRI obtained with the same TR and TE, corresponding to three different EPI echo train lengths (2, 4 and 32). It can be seen that virtually the same contrast and quality can be achieved with massively accelerated MRI protocols, after removing Nyquist artifacts with the phase-cycled reconstruction. Figure 2b shows that high-quality and high-throughput MRI of different contrasts (T2* and IR) can also be reliably achieved with the developed EPI-accelerated method. Our experimental and numerical data suggest that the image quality, in terms of the FWHM of the point-spread function (related to the T2*-decay within EPI echo trains), changes only insignificantly when using an acceleration scheme with a small echo train length (Figure 2c: PSF-FWHM increases by <5% for ETL=8; <10% for ETL=16; <20% for ETL=32).

Discussion and conclusion

Experimental data from our studies strongly suggest that it is feasible to accelerate various clinical MRI protocols, without sacrificing the image quality, using segmented echo-planar readout waveforms. The Nyquist artifacts associated with the EPI readout can be effectively removed with phase-cycled reconstruction [1], without needing any reference scan. Our acquisition and reconstruction scheme can be integrated with parallel imaging, for further acceleration. This approach should prove highly valuable for MRI studies in challenging patient populations (e.g., children, seriously ill patients and claustrophobic individuals).

References

[1] Chen NK, Avram AV, Song AW. Two-Dimensional Phase Cycled Reconstruction for Inherent Correction of Echo-Planar Imaging Nyquist Artifacts. *Magn Reson Med* 66(4):1057-66, 2011

Figure 1

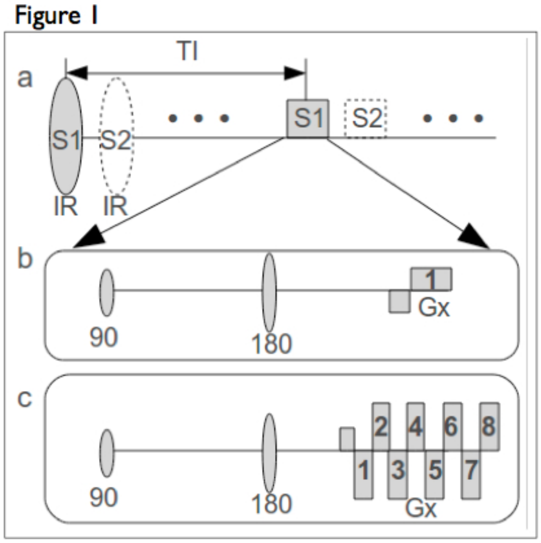

Figure 2