Image domain Propeller FSE (iProp-FSE)

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Introduction: Fast-spin echo (FSE) imaging is one of the most frequently used pulse sequences for brain imaging due to its scan time efficiency, good tissue contrast, and high effective resolution. Practical problems that occur are mostly due to patient motion, which leads to blurring and imaging ghosting (Fig. 1b). To make the acquisition robust to motion, the T_2-w PROPELLER pulse sequence can be used[1], where each excitation is followed by an RF-refocused blade readout in *k*-space that rotates between acquisitions (Fig. 2a). In our experience however, the contrast of FSE is still preferred over PROPELLER, as our neuroradiologists find that the latter has less GM/WM conspicuity. Hence, in practice, one faces the trade off between optimal contrast and the risk of motion artifacts.

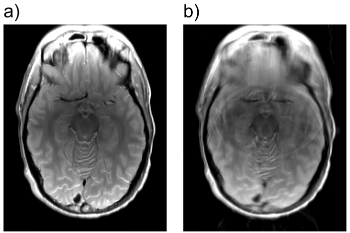

Figure 1. a) Fast Spin Echo image using a 32-channel head coil. b) Same as a, but with head motion. These images highlights the rationale behind this work: 1) Overcome the close to radially varying SNR. 2) Use an image sampling scheme that is robust to motion

In this work, we present a new pulse sequence, *image domain Propeller FSE* (iProp-FSE), whereby propeller blades are acquired in the image domain instead of in *k*-space (PROPELLER), with the phase encoding direction aligned with the short-axis of the blade as in PROPELLER. Similar to PROPELLER, iProp-FSE also allows one to perform motion correction, but there are considerable differences between both sequences. Specifically, iProp-FSE has three useful properties: (1) the overlap of blades occurs in the image domain, whereby N_{blades} averages are obtained in the center of the brain, which is the most SNR-starved region for 'multi'-channel coils. Unlike PROPELLER, this approach comes without the penalty of colored noise; (2) Even if each blade covers only a strip of the final FOV, there is plenty of overlap between adjacent blades, making motion correction straightforward; (3) Since the image phase of the blade does not need to be preserved when combining the blades in the image domain, the gridded image is immune to potential spatially-varying non-linear phase changes, such as seen in DWI.

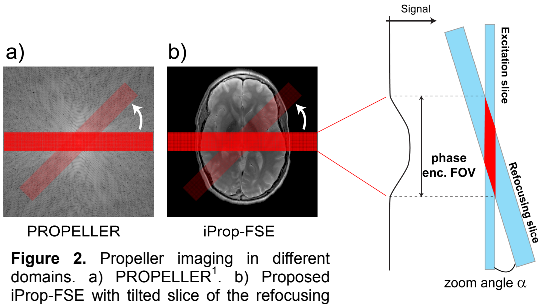

Figure 2. Propeller imaging in different domains. a) PROPELLER[1]. b) Proposed iProp-FSE with tilted slice of the refocusing pulse to avoid aliasing in the phase encoding direction.

Materials and Methods: To avoid aliasing in the phase encoding direction, we tilted the refocusing slice-select pulse relative to the excitation pulse plane by a 'zoom angle' (α), similar to work introduced by Mansfield et al.[2] for EPI. An axial brain slice of a healthy volunteer was acquired on a GE 3T Discovery MR750 system equipped with a 50 mT/m, SR=200 T/m/s gradient system using a 32-channel head coil (MRI instruments Inc., Minneapolis, MN). The iProp-FSE sequence was used with the following relevant imaging parameters: FOV = 28×3.5 cm (8:1 ratio), α = 30°, 4 mm excitation slice thickness, 8 mm for the refocusing pulses with a flip angle of 125°, ETL= 32, TE$_{\text{eff}}$/TR = 10/4000 ms, and a receiver bandwidth of ±32 kHz. 32 blades of size 256×32 (freq.×phase) were rotated isotropically over 0-174.4°. Note that due to the slice tilt of the zoom approach the selected blade is non-uniform along the short axis of the blade. Thus, the scan was repeated on a homogeneous phantom to measure the combined sensitivity profile from the receiver coils and the across-blade signal modulation (Fig. 2b) for the given zoom angle. Each blade was gridded separately (essentially a simple rotation) to form the final image. First, the phantom data were gridded to obtain the combined sensitivity profile. This, in fact, also resembles the sampling density of all blades. Thereafter, this sensitivity profile was used to weight each of the brain blade data prior to the final image blade combination.

Results: Figure 3, shows how the image gradually forms as more blades are included in the reconstruction. In the rightmost panel, all blades have been used and - for this particular scan - the brain stem has now been averaged 32 times, leading to a local SNR increase of $\sqrt{32}$ =5.6 times. Thanks to the measured coil sensitivity profiles, the signal across the brain is also homogeneous aside from the SNR improvement. A corresponding slice acquired using conventional FSE is given in Fig. 1a (NB: this is neither scan time matched nor is it reconstructed with coil sensitivity compensation).

Discussion: We have presented a new pulse sequence named iProp-FSE that could be an interesting alternative for T_2-w brain imaging. This approach does not suffer from colored noise and is well-suited to 32+ channel RF head coils. With such coils the SNR is vastly improved near the coil elements, whilst it drops rapidly towards the center of the coil. By averaging the central region more often the high SNR periphery, iProp-FSE attempts achieve the same SNR for the entire brain. We will now continue to improve the sequence in a variety of aspects. Firstly, motion correction will be implemented. Secondly, the best choice of zoom technique will be investigated[2,3]. Thirdly, the blades should ideally become somewhat wider, however not too wide to introduce T_2-blurring that is pronounced in Cartesian SSFSE. For the widening of the blades, half-Fourier imaging, bandwidth selections, parallel imaging, and RF pulse trade-offs will be explored to minimize blurring. This will broaden the SNR 'hotspot' created by the blade averaging in the center of the brain. Currently this leaves a ring of lower SNR between the averaging area and the edges of the FOV with high SNR (due to the proximity to the receiver coils). Without any loss of motion correction ability, further control of the broadening of the central blade averaging region can be achieved by not permitting all blades pass through the same point. We will also investigate if the image contrast of iProp-FSE is more similar to Cartesian FSE than PROPELLER.

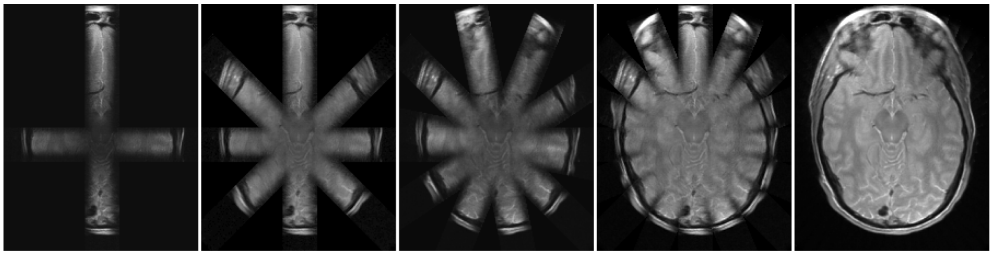

Figure 3. Image domain propeller FSE (iProp-FSE) reconstructions using 2-32 iProp blades. In the final image, the SNR in the posterior part of the brain stem was increased 5.6 times. In addition, the measured coil sensitivities also allowed for signal intensity compensation due to the coils.

Acknowledgements: This work was supported in part by the NIH (5R01EB002711, 1R21EB006860, 1R01EB008706, 1R01EB006526, the Swedish Research Council (K2007-53P-20322-01-4), the Center of Advanced MR Technology at Stanford (P41RR09784), the Oak Foundation and the Lucas foundation. Thanks to our neuroradiologist Dr. Greg Zaharchuk for his useful comments.

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