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Original contributions

Image domain propeller fast spin echo ☆

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ABSTRACT

A new pulse sequence for high-resolution T2-weighted (T2-w) imaging is proposed — image domain propeller fast spin echo (iProp-FSE). Similar to the T2-w PROPELLER sequence, iProp-FSE acquires data in a segmented fashion, as blades that are acquired in multiple TRs. However, the iProp-FSE blades are formed in the image domain instead of in the *k*-space domain. Each iProp-FSE blade resembles a single-shot fast spin echo (SSFSE) sequence with a very narrow phase-encoding field of view (FOV), after which *N* rotated blade replicas yield the final full circular FOV. Our method of combining the image domain blade data to a full FOV image is detailed, and optimal choices of phase-encoding FOVs and receiver bandwidths were evaluated on phantom and volunteers. The results suggest that a phase FOV of 15–20%, a receiver bandwidth of ±32–63 kHz and a subsequent readout time of about 300 ms provide a good tradeoff between signal-to-noise ratio (SNR) efficiency and T2 blurring. Comparisons between iProp-FSE, Cartesian FSE and PROPELLER were made on single-slice axial brain data, showing similar T2-w tissue contrast and SNR with great anatomical conspicuity at similar scan times — without colored noise or streaks from motion. A new slice interleaving order is also proposed to improve the multislice capabilities of iProp-FSE.

1. Introduction

For nearly all patients undergoing MRI today, high-resolution T2-weighted (T2-w) imaging plays a key role in the examination. For T2-w image contrast, the fast spin-echo (FSE) sequence [1] is typically used due to its good contrast and SNR efficiency — with image artifacts mostly limited to image ghosting caused by patient motion.

To avoid image ghosting due to head motion, the T2-w PROPELLER pulse sequence [2,3] has been implemented as an alternative to FSE and is currently available on most commercial MR systems. In PROPELLER, the RF-refocused echoes in the readout train are placed as a rectangular strip, or blade, over the center of *k*-space with the 'length' of the blade along the frequency-encoding direction. The remaining areas of *k*-space are acquired in subsequent TRs by rotated replicas of the *k*-space blade trajectory (hence, the acronym PROPELLER). With its centrally overlapping blades, PROPELLER is a self-navigated technique, allowing for both image domain phase correction (that centers and focuses the blades in *k*-space) as well as in-plane (2D) motion correction between the blades. Because all blades cover the center of *k*-space, a noise-suppressing averaging effect results for low spatial frequencies, and the remaining high-frequency noise may render the image somewhat 'speckled' if the overall SNR is limited.

In this article, we present a new pulse sequence, *i*mage domain *Prop*eller *FSE* (iProp-FSE), where data are collected in a similar propeller fashion to PROPELLER, but where the blades are formed and stitched together in the image domain. While each *k*-space PROPELLER blade constitutes a full FOV image at low resolution along the phase-encoding direction (Fig. 1A), an iProp-FSE blade covers a narrow strip of the image FOV at *full* image resolution (Fig. 1B), with the phase-encoding FOV (FOV_{phase}) and frequency-encoding FOV (FOV_{freq}) along the short and long axes, respectively. Subsequent blades are rotated around the center of the image FOV to cover the rest of the missing anatomy. The blade overlap that occurs at the center of the image FOV effectively produces a local averaging effect (NEX) corresponding to N_{blades}. For regular head exams, the center of the FOV is typically the most SNR-starved area, as it usually coincides with the location that is furthest away from the coil elements. For example, the SNR at the brain's cortex near the coil elements may be about three to five times higher than that at the brain stem for a 32-channel head coil (Fig. 3A). With overlapping image domain blades, the low SNR at the center of the coil is compensated for by more local averages centrally, which helps to even out the SNR over the entire brain.

However, to make the iProp-FSE to work in practice, the first step is to overcome the aliasing of anatomy located outside the narrow blade FOV along each blade's phase-encoding direction. Previous

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work (in the context of diffusion imaging), including zonally magnified (ZOOM) EPI [4], contiguous slice zoom EPI [5] and reduced FOV techniques for spine imaging [6], has, in various ways, shown how a rectangular image FOV can be obtained without aliasing. Common for these methods is that the excitation and refocusing slice planes are played out at an angle relative to each other to avoid signal outside the intended FOV. For iProp-FSE, we have chosen to avoid aliasing outside the phase-encoding FOV by tilting the excitation pulse by a relatively low tilt angle, with the train of refocusing pulses played out in the prescribed image plane.

Deng and Larson [7] have recently proposed a related T2-w PROPELLER technique using an out-of-plane excitation, dubbed *targeted PROPELLER MRI*, where only a part of the anatomy is shown in the final image. In Ref. [7], standard *k*-space gridding was performed with the final image corresponding to the intersecting area of the iProp-FSE blades presented in this work.

The main objectives of this initial study on iProp-FSE were to investigate

1. how the iProp blades are to be combined seamlessly in the image domain (weighted image-domain gridding).
2. how the effective resolution and SNR are affected by the echo train length, controlled by the choice of receiver bandwidth and the blade width (FOV_{phase}) for a given target resolution.
3. the amount of reduction in SNR and image contrast for contiguous multislice iProp-FSE imaging due to the out-of-slice saturation effect from the tilted slices.
4. whether iProp-FSE can yield a high-resolution T2-w image contrast with a SNR efficiency similar to the commercially available FSE and PROPELLER sequences.

2. Methods

2.1. Data acquisition

The iProp-FSE sequence is, in many ways, similar to the single-shot fast spin-echo (SSFSE) pulse sequence [8,9], but with a significantly reduced FOV_{phase}, with N_{blades} dynamically rotated replicas of the prescribed FOV and with an extra gradient added along the phase-encoding direction during the excitation (Fig. 2A). With a linear combination of the two slice selective excitation gradient amplitudes, the resulting excitation slab is played out at a given angle in the slice/phase-encoding plane, with a slab thickness that was automatically adjusted based on the prescribed FOV_{phase} (Fig. 2B and C).

Due to the tilted excitation plane, only spins experiencing both the excitation and the refocusing pulses contribute to the MR signal (green area, Fig. 2B and C). For any excitation tilt angle below 90°, the slice thickness will consequently approach zero at the edges of the

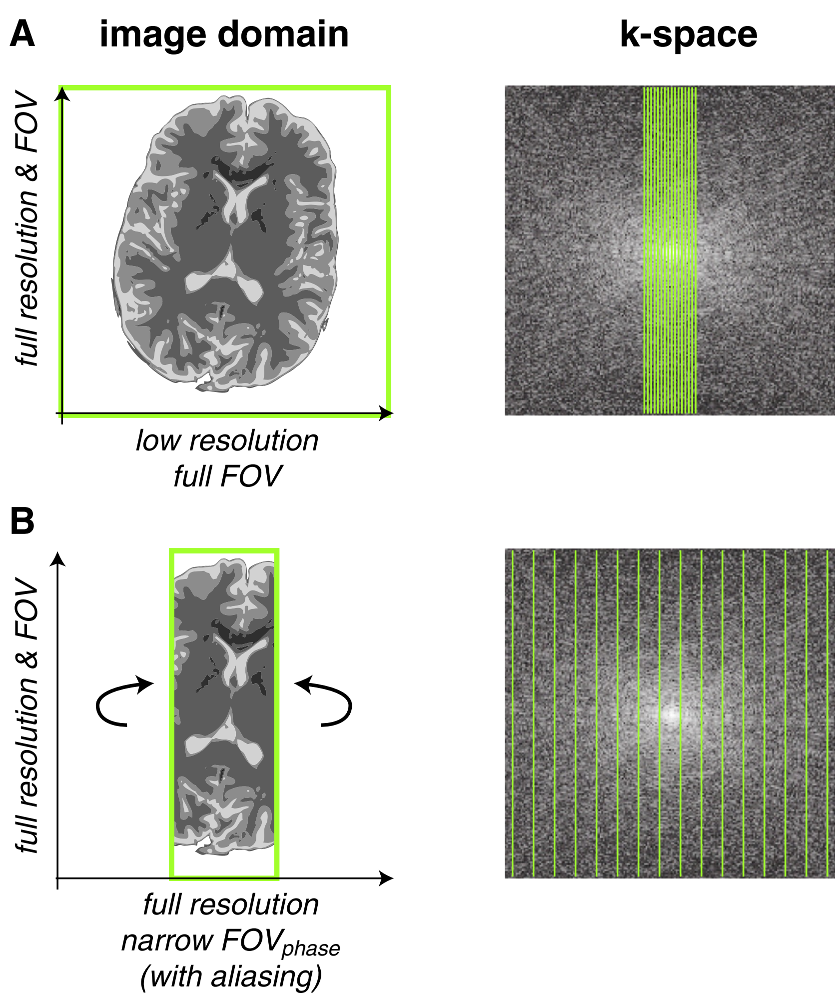

Fig. 1. Illustration of the *k*-space propeller (A) and the image space propeller (B) trajectory (this work). In (A), the *k*-space blade corresponds to a full FOV image with low resolution along the phase-encoding direction. In (B), the image domain blade has the same image resolution as the final image, but with a reduced phase-encoding FOV, leading to aliasing if not accounted for.