Accelerating a Spectrally-Resolved Fully Phase-Encoded (SR-FPE) Method for Metal Artifact Reduction

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PURPOSE A spectrally-resolved fully phase-encoded (SR-FPE) method was recently introduced for metal artifact reduction and spectroscopic imaging.[1] This technique phase-encodes all three spatial dimensions and collects spectral data using an extended echo train 3D-FSE acquisition. The primary limitation of SR-FPE is long scan time. Fortunately, it possesses two distinct advantages for acceleration: 1) the spectral data result in very high SNR through effective averaging and 2) *k*-space points are acquired independently offering significant flexibility in the 3D sampling pattern. The purpose of this work was to demonstrate the feasibility of clinically acceptable scan times using parallel imaging in all 3 phase-encoding directions in combination with corner cutting and half-Fourier sampling.

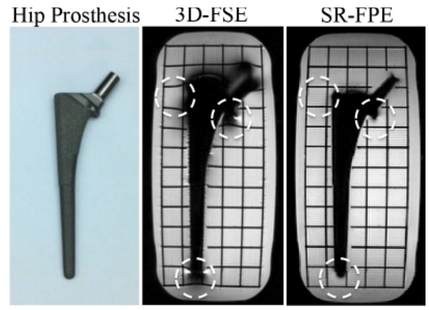

Figure 1 *SR-FPE avoids the distortion visible in conventional 3D-FSE (dashed white circles).*

METHODS The femoral component of a titanium hip prosthesis was placed within a plastic grid and submerged in undoped water. To compare distortion between conventional 3D-FSE and SR-FPE, this phantom was first scanned at 1.5T using a single channel T/R head coil. SR-FPE acquisition parameters included: FOV=23x11.5x4.8cm^3, matrix=240x120x24, TR=1.0s, ETL=24, receiver BW=±7.8kHz, TE_{eff}=71ms, linear *k*-space encoding, scan time=8hrs. A single ADC sample from the center of the echo (DC image) was reconstructed and compared to a conventional 3D-FSE image acquired with a matrix=256x128x24, ETL =24, receiver BW=±31.25kHz, TE_{eff}=34ms, scan time=1:41min.

The feasibility of SR-FPE scan time reduction was investigated by acquiring fully-sampled (FS) data using a 16-channel wrap array (NeoCoil, Pewaukee, WI) at 1.5T. This was a receive-only coil with limited RF transmit power, requiring a longer RF pulse width to maintain flip angles needed to perform FSE imaging. Although this lowered the excitation bandwidth and limited our ability to excite all off-resonance spins, it did not impact the primary purpose of the scan – acquisition of a FS, multi-channel data set acquired to compare accelerated results with FS ground truth. SR-FPE scan parameters included: FOV=24x12x10cm^3, matrix=240x120x50, ADC samples=16, receiver BW=±2.5kHz (313Hz spectral resolution), TR=1.2s, ETL=120, TE_{eff}=390ms, linear *k*-space encoding, scan time=4hrs.

Fully-sampled kx/ky/kz data were retrospectively under-sampled (US) using 3D ellipsoid corner cutting[2] (CC) and parallel imaging (PI) in all three phase-encoding directions ($R_xxR_yxR_z$=3x2x2). Prospectively under-sampling in this manner would lead to an effective (eff) scan time of $12min_{eff}$. A 3D-GRAPPA reconstruction[3] was performed for each ADC sample using an auto-calibration region of 25x25x25 and a kernel size of 7x5x5. For both the FS and US data, spectral modeling[1] was performed to estimate the water signal ($\rho_w(\mathbf{r})$), B_0 field inhomogeneity ($\Psi(\mathbf{r})$), and R2*($\mathbf{r}$). Error images were calculated to show differences between FS and US images.

In a separate test, for the central ADC sample alone (DC image), 52% half-Fourier (hF) was applied in the longest dimension in addition to the CC and PI described above, reducing the $scan_{eff}$ to 7.5min. POCS was performed following GRAPPA to reconstruct full-resolution images.

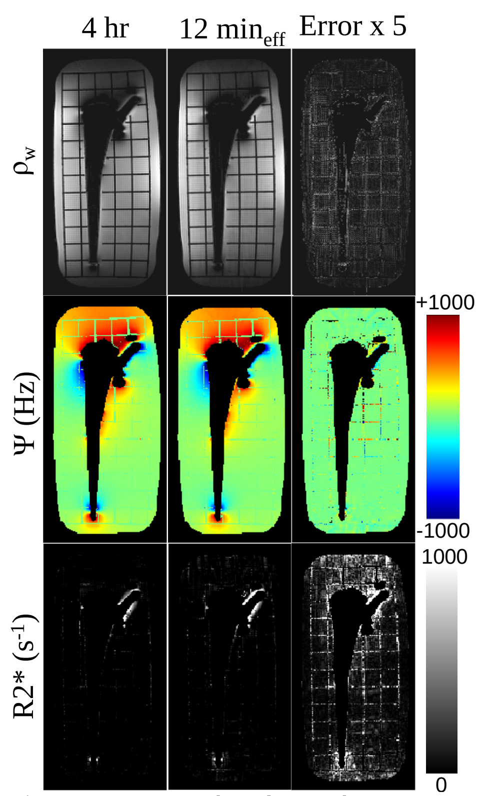

Figure 2 *Retrospectively under-sampling SR-FPE via ellipsoid CC and GRAPPA ($R_xxR_yxR_z$=3x2x2) produced spectral modeling results comparable to the fully-sampled data with an effective scan time of 12 min.*

RESULTS AND DISCUSSION The hip prosthesis and surrounding grid were well-depicted with SR-FPE, while 3D-FSE demonstrated susceptibility-related distortion (white circles, **Fig 1**). Mild warping is noticeable because manufacturer gradient non-linearity corrections were not applied. Retrospective under-sampling via ellipsoid CC and PI produced spectral modeling results comparable to the FS data with an effective scan time of 12min (**Fig 2**). Acceleration results using CC, PI, and hF on the DC image successfully depicted the structures and would reduce the effective scan time from 4hr to 7.5min (**Fig 3**). Note that the RF-based signal dropout visible in Fig 2 and 3 can be avoided in the future by interleaving multiple acquisitions at different radiofrequency offsets within the same TR (similar to the MAVRIC/SEMAC hybrid[4]) without an increase in scan time.

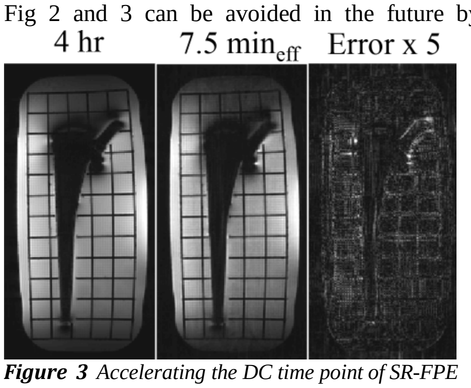

Figure 3 *Accelerating the DC time point of SR-FPE using ellipsoid CC, GRAPPA, and 52% half-Fourier successfully depicted all structures in the image, reducing the effective scan time from 4 hr to 7.5 min.*

CONCLUSION To our knowledge, this is the first implementation of PI acceleration in three dimensions using Cartesian data. The accelerated results successfully depicted structures and spectral data comparable to the FS ground truth, providing strong evidence that SR-FPE can be accelerated to clinically feasible scan times.

REFERENCES [1]Artz et al. ISMRM 2012 #2431. [2]Bernstein et al. 2001;14:270-80. [3]Griswold et al. MRM 2002;47:1202-10. [4]Koch et al. MRM 2011;65:71-82.

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