Improved spatial localization in 3D MRSI with a sequence combining PSF-Choice, EPSI and a resolution-enhancement algorithm

L. P. Panych[1], B. Madore[1], W. S. Hoge[1], and R. V. Mulkern[2]
[1]Radiology, Brigham and Womens Hospital, Boston, MA, United States, [2]Radiology, Children's Hospital, Boston, MA, United States

Introduction

Gibbs ringing is an artifact frequently encountered in MRSI. A standard method to suppress this artifact, which is caused by truncation in k-space, is to apply a low-pass filter. Although this effectively removes the artifact, it does so at the expense of spatial resolution. One proposed method, PSF-Choice, eliminates this artifact using a special scheme to manipulate the RF excitation on each phase-encode step, thereby modifying the point-spread-function (PSF) [1]. Unlike the low-pass filtering approach, PSF-Choice maintains the original spatial resolution. The method has previously been implemented and evaluated for prostate MRSI, with PSF-Choice encoding along one dimension [2]. Here, we report the implementation of PSF-Choice along two phase-encoding dimensions with echo-planar spectroscopic imaging (EPSI) implemented along the third dimension. A resolution enhancement approach [3] suitable for use with PSF-Choice is also demonstrated.

Methods

PSF-Choice: A PRESS spectroscopic imaging sequence on a GE 3T MRI system was modified for PSF-Choice encoding in x and y by replacing the 90-degree excitation pulse with a train of 4 hard RF pulses separated by x and y gradient pulses. The resultant RF pulse can be thought of as a highly under-sampled 2D excitation pulse where the fully-sampled pulse is designed to excite a 2D Gaussian profile. Excitation k-space under-sampling causes multiple Gaussian-shaped excitation profiles to be excited. However, with a series of phase encoding steps, the signal under each Gaussian profile is encoded and can be reconstructed.
EPSI: An EPI gradient train of 512 gradient pulses (with alternating polarity) was added to the sequence during acquisition of the FID. Each gradient pulse frequency-encodes spins along one axis. Unlike EPI, however, there are no phase encode blips applied along the echo-planar train. After proper sorting of the data, including correcting for the time delay between acquisition and the echo-planar gradient waveform, a 4D Fourier transform is applied to reconstruct 3 spatial dimensions and one spectral. With EPSI, one direction is encoded in a single shot, greatly speeding the acquisition time but with a penalty in SNR loss. To recover some SNR, multiple EPSI acquisitions can be averaged.
Multiple acquisitions and enhanced-resolution reconstruction: Rather than repeating EPSI acquisitions exactly, we shift the spatial sampling grid on each of 4 acquisitions with the centers (x,y) positioned at [0,0], [dx/2,0], [0,dy/2] and [dx/2,dy/2] where dx and dy equal to the pixel dimensions in x and y respectively. After reconstruction, the 4 image arrays are interleaved in the x and y directions, thereby doubling the image matrix size in both directions. Note that the resolution in the x-y plane is not increased by interleaving since each image set is still only acquired at the resolution dx,dy. However, since the Gaussian PSF of our method contains spatial frequencies greater than 1/dx and 1/dy, we can apply a super-resolution approach [3] as shown below.

Figure 1

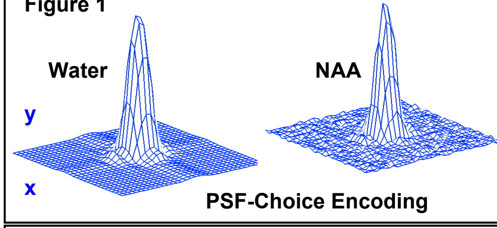
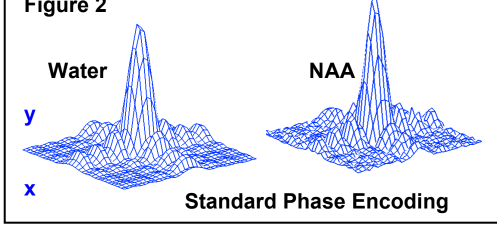


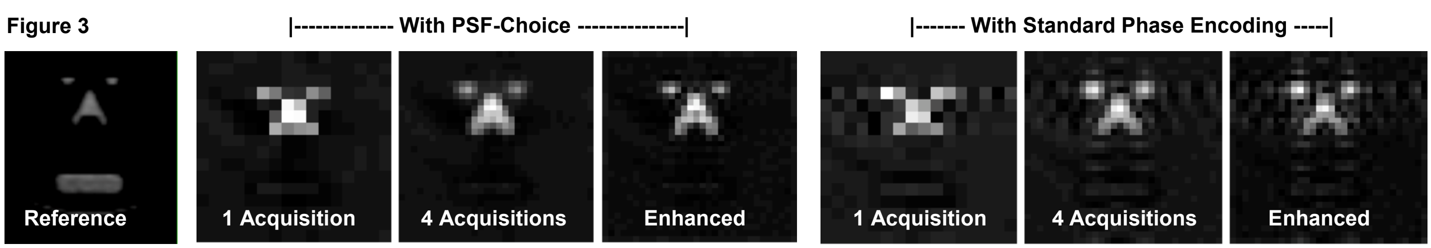
Figure 2



Results

Verification of PSFs: Figures 1 and 2 show 2D PSFs (at water and NAA peaks) obtained from measurements in a spectroscopy phantom for PSF-Choice (Fig.1) and standard phase encoding (Fig.2). The PSFs are obtained by selecting a PRESS voxel with dimensions smaller than the size of the image voxel. Then, 16 acquisitions were obtained with quarter-voxel shifts in each direction and the image datasets were interleaved. Note that the PSF for standard phase encoding is sinc-like as expected. Other than SNR differences, the same characteristics are seen for both water and NAA.
Image interleaving and resolution enhancement: Figure 3 shows results obtained using a resolution phantom with 4 acquisitions shifted as described above. Images shown are from the water peak. Artifact due to k-space truncation is seen in all the images reconstructed with standard phase encoding (right side of Fig.3). The images obtained with PSF-Choice, however, have no such artifact. It should be noted that the inherent spatial resolution of the single acquisition images is actually no lower than it is with the 4 image sets interleaved. The interleaved image sets only appear to be better because of the interpolating effect of shifting the acquisitions by half the pixel dimension. However, with PSF-Choice we are able to obtain enhanced resolution (with some noise amplification) from the 4 lower resolution image sets because the Gaussian PSF probes higher spatial frequencies than the sinc-like PSF. This is seen by inspection of the 'Enhanced' images for the two methods in Fig.3.

Figure 3



Summary and Discussion

PSF-Choice produces MR spectroscopic images free of truncation artifact. Also, when combined with EPSI for acceleration, multiple low-resolution images sets can be acquired and then combined for resolution enhancement in the PSF-Choice encoding directions. As an alternative to resolution enhancement, which has a penalty in SNR, the multiple image sets can always be combined with an averaging filter to maximize SNR.

References: [1] Panych et al. Magn Reson Med. (2005) 54:159-68. [2] Panych et al. ISMRM 2009, p.335. [3] Irani & Peleg. ICPR. (1990) 115-120.

Acknowledgements: Supported by NIH grants R33-CA110092 and P41-RR019703.