Factor-2 acceleration for 3D EPSI at 4T using modified blipped phase-encoding

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Introduction

To reduce acquisition time, T_A, at given spatial resolution for echo-planar spectroscopic imaging (EPSI), Webb et al. [1] suggested application of a blipped phase-encoding (PE) gradient in between even and odd lobes of the readout (RO) gradient, which accomplishes phase-encoding of the even RO echoes in k-space at an interstitial location along k_{PE} (Fig 1a). Thus, the number of PE steps, and hence T_A, could be reduced by a factor of 2 with a concomitant reduction in SNR. However, the approach is very susceptible to phase inconsistencies between the even and odd RO echoes due to B_0 inhomogeneities and gradient imbalance, which leads to ghosting in the PE direction. We propose to place the blipped PE gradient in between pairs of even/odd RO gradient lobes (Fig. 1b), which should – for reasons of symmetry – prevent phase inconsistencies between even and odd echoes from interfering with the phase-encoding. Feasibility of this approach is demonstrated for 3D EPSI in normal human brain in vivo at 4T.

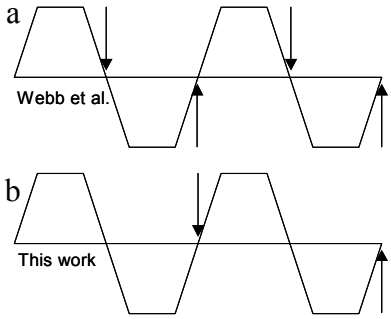

Figure 1: Trapezoidal RO gradient and blipped PE gradient (arrows).

Methods

A previously described 3D EPSI pulse sequence [2] implemented on a Bruker MedSpec 4T system with Siemens Sonata gradients was modified to introduce phase-encoding blips between consecutive pairs of even/odd RO gradient lobes. The trapezoidal lobes had a duration of 350 μs with 120 μs ramps. During the central 288 μs, 48 samples were taken equidistantly in time with an oversampling factor of 2. Triangular phase-encoding blips with a ramp time of 30 μs were applied during the sampling-free portion of the final ramp of every other lobe. Polarity was reversed for every other blip to switch back from the interstitial k_{PE} location (Fig. 1b). Acquisition parameters were FOV=320x320x180 mm^3 (RO.PE.slice), TR/TE/TI=1780/45/280 ms, matrix size=48x25x18x1200 (RO.PE.slice. time), and T_A=13.5 min. for whole-brain coverage of a 160 mm axial slab. This sequence allowed acquisition of a spectral width of 4.25 ppm after separation of RO echo pairs. Spatial resolution had to be reduced slightly as compared to [2] from 0.32 mL to 0.42 mL (nominal) to limit peripheral nerve stimulation. After reordering of the phase-encoded RO echoes, data were processed as described previously [2]. The effective voxel size was approximately 2.7 mL after spatial smoothing.

Results and Discussion

In Fig. 2 are shown images of NAA (2.01 ppm) obtained by spectral integration (top) and automated spectral fitting [3] (bottom). A residual ghost is visible in PE direction (R–L), which is related in part to a spectral Nyquist artifact that apparently scales with signal intensity in the original image location. This may be due to residual zero-order phase errors between RO echo pairs caused by eddy currents.

Furthermore, subject movement may cause phase-encoding errors that result in ghost artifacts. No metabolite signal could be detected in the regions of the ghost.

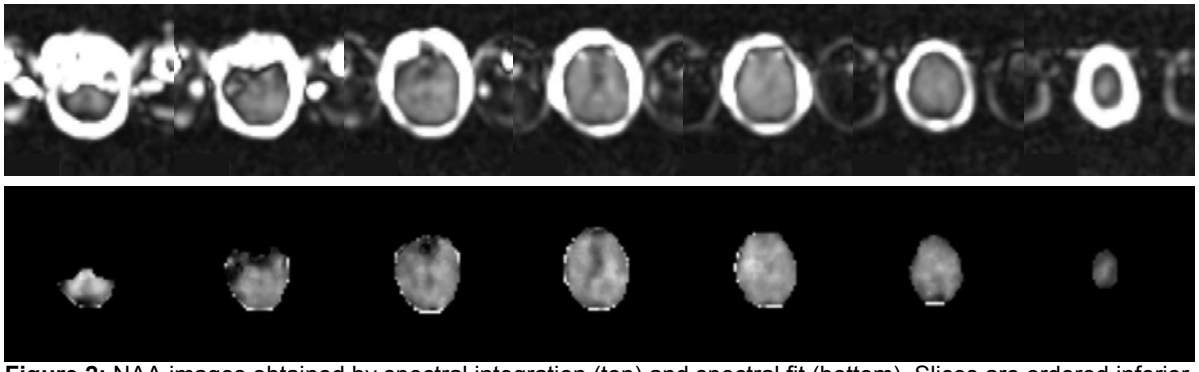

Figure 2: NAA images obtained by spectral integration (top) and spectral fit (bottom). Slices are ordered inferior to superior from left to right.

Conclusions

Blipped phase-encoding for 3D EPSI is feasible at 4T, allowing reduction of the acquisition time by a factor of 2 (T_A=13.5 min. for whole-brain coverage). A residual Nyquist ghost remains with possible spatial overlap with the brain (for larger heads). In most slices, spectral overlap is limited to a baseline bias, but this should not cause problems for the automated spectral fitting procedure used. Fine-tuning of the phase correction between RO echo pairs, as well as improved water suppression and outer volume saturation of signal from below the EPSI slab are expected to reduce the artifacts. Blipped phase-encoding is also compatible with parallel imaging, and both techniques together should achieve clinically acceptable scan times for 3D EPSI.

References: [1] Webb P, et al. Magn. Reson. Med. 12:306 (1989). [2] Ebel A, et al. Magn. Reson. Med. 54:697 (2005). [3] Soher BJ, et al. Magn. Reson. Med. 40:822 (1998).