Optimization of a Zero Echo Time (ZTE) Sequence at 7T with Phased Array Coils

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Target Audience: MR physicists and engineers, neuroradiologists, neuroscientists

Purpose: To develop and validate a zero echo time (ZTE) imaging sequence compatible with array receivers with robust contrast in human brain at 7T

Methods: A zero echo time (ZTE) sequence based on a 3D radial acquisition[1] was implemented for a 7T human research system (GE MR950, 7T23 software, Waukesha WI). Optimizations consisted of redesign of the inversion pulse, replacement of the fat suppression pulse, and optimization of the scan timing parameters (number of spokes per segment, inversion preparation delay, and post-segment recovery delay). Optimization of the inversion pulse began with analysis of in vivo |B1+| maps generated with a Bloch-Siegert B1 mapping sequence[2] incorporating a lower power frequency modulated Bloch-Siegert pulse[3]. B1 maps were generated over 5 mm slices at 10 mm intervals on a 64x64 matrix. After scaling to the desired transmitter gain, histograms were generated and the 5th percentile B1 over the volume was determined to be 9.5 μT. An HS2[4] reduced power adiabatic inversion pulse with a 20 ms duration, a cutoff parameter (β) of 5.283, and a 25 kHz sweep amplitude was designed and simulated by generating the Cayley-Klein parameters for the pulse for a range of frequency offsets and B1 amplitudes; with these parameters the pulse was found to be fully adiabatic over 1 kHz for B1 amplitudes above 9.2 μT as shown below. For the fat suppression pulse, a time-bandwidth product of 5 was chosen with maximum phase, designed using the Shinnar-LeRoux algorithm[5] and played out with a duration of 8 ms. For sequence timing optimization, T1 relaxation times for cortical grey matter and white matter[6] were used to calculate the available magnetization in steady state given the preparation time for a range of post-segment recovery delays, and the maximum signal difference which would allow a 5 minute scan time for the desired resolution was selected. Images were acquired with 1.1 mm isotropic voxels over the whole brain, 62.5 kHz bandwidth, 384 spokes per segment, 1 second post-segment delay, 650 ms inversion prep delay, 5 minute total scan time (the same scan time as a commonly used IR-prepared fast 3D gradient echo protocol), Nova 32 channel receiver array with 2 channel CP transmitter. Images were acquired of volunteers under a protocol approved by the Committee on Human Research.

Results and Discussion: Example images from a volunteer are shown below in Figures 1-3 along axial, sagittal and coronal planes, without receiver sensitivity correction. Of particular note are the visibility of the skull and related structures, as well as the foam padding supporting the head and some components of the RF coil. Some diffuse signal is present in the background as well as some star artifacts from the interpolation kernel. Otherwise the contrast between grey and white matter is consistent across the brain. Figure 4 shows the effect of the post-segment delay, significantly decreasing the contrast as expected from the steady state inversion recovery model.

Conclusion: The silent sequence as adapted for 7T – matching the inversion pulse to the available B1, increasing the fat suppression pulse bandwidth, and optimizing the sequence timing -- provides improved grey-white contrast over the whole brain in equivalent scan time compared to IR prepared 3D fast gradient echo. The sequence also allows imaging of short T2 structures.

References: 1. Madio D and Lowe MRM 34:4 pp 525-9 1995. 2. Sacolick L et al MRM 63:5, pp 1315-22, 2010. 3. Khalighi M, et al. MRM 70:3 pp 829-35 2013. 4. Tannus and Garwood NiB 10:8 pp 423-34 1997. 5. Pauly J et al IEEE TMI 10:1 pp 53-65 1991. 6 Rooney W. et al. MRM 57:2 pp 308-18 2007.