Practical Non-selective Refocusing Pulses for 7 T MRI

M. Jankiewicz[1,2], J. Moore[1,3], A. Anderson[1,4], and J. Gore[1,4]
[1]Institute of Imaging Science, Vanderbilt University, Nashville, TN, United States, [2]Radiology and Radiological Sciences, Vanderbilt University, Nashville, TN, United States, [3]Physics and Astronomy, Vanderbilt University, United States, [4]Biomedical Engineering, Vanderbilt University

Introduction

Imaging sequences reliant upon non-selective refocusing (e.g., 3D TSE, 3D GraSE, and 3D SE-EPI) widely employ either block/sinc refocusing pulses susceptible to field inhomogeneities or adiabatic pulses that demand high SAR. The aim of this work was to evaluate a sample of short, low-SAR, non-selective refocusing pulses by comparing signals acquired with a 3D SE-EPI sequence at 7 T. In reference to a 180° block pulse, all pulses result in overall signal gains with some pulses increasing signal by more than a factor of 2 in localized areas. SAR increases for all pulses are less than 2-fold with respect to the block pulse. This work thus demonstrates what signal improvements are possible under the condition that scan duration be minimally impacted and therefore aids high-field researchers and clinicians in choosing suitable refocusing pulses for practical 3D spin-echo imaging.

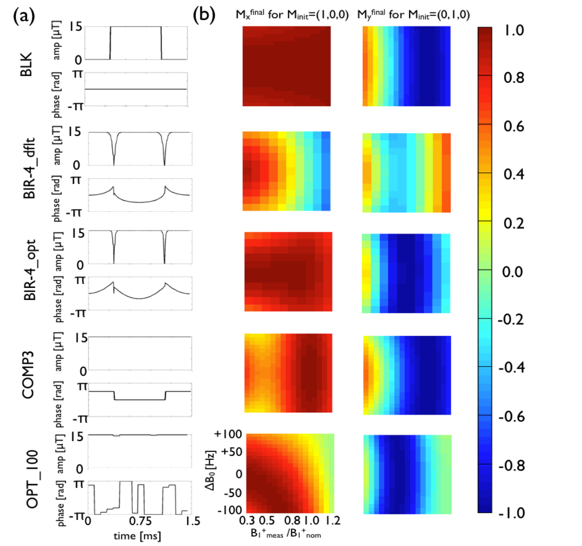

Fig.1: (a) Waveforms of BLK, BIR-4_dflt, BIR-4_opt, COMP3, and OPT_100 pulses and (b) corresponding components of the refocused transverse magnetization for initial conditions (M_x,M_y,M_z) = (1,0,0), (0,1,0), and (0,0,1).

Methods

On a Philips 7 T scanner with a volume T/R head coil (maximum RF amplitude = 15 µT), we implemented 5 non-selective refocusing pulses: a 180° block (BLK), a 1.5 ms composite $90°_x$-$180°_y$-$90°_x$ (COMP3) **[1]**, a 1.5 ms BIR-4 (BIR-4_dflt) designed according to **[2]**, a 1.5 ms numerically optimized BIR-4 (BIR-4_opt) designed according to **[3]** and **[4]**, and a 1.5 ms, numerically optimized, 16-part composite pulse (OPT_100) designed similarly to **[4]**. For BIR-4_opt and OPT_100 pulses, amplitude and phase modulations were determined by minimizing a cost function over a grid of B_1^+ and ΔB_0 ranges representing typical variations in the human brain at 7 T **[5]**. Using a 17 cm spherical dielectric phantom from fBIRN, four 3D spin-echo experiments (T_E/T_R = 50/5000ms) with a 90° block excitation and a single-shot EPI read-out were performed, each with a different refocusing pulse. As a simple evaluation of SAR, the minimum T_R allowed by the scanner for each sequence was recorded. EPI distortion corrections were performed using ΔB_0 maps generated from a 3D GRE double-echo scan (ΔT_E = 1 ms) while B_1^+ maps were calculated for the imaging volume via a voxel-by-voxel fitting of signal intensities from a multi-flip-angle, multi-slice, single-shot GRE-EPI scan (T_R = 5000 ms).

Results and Conclusions

Waveforms of the refocusing pulses and simulated magnetization responses for various initial conditions are shown in Fig. 1. In addition to (a) B_1^+ and (b) ΔB_0 maps for 7 axial slices of the phantom, Fig. 2 shows 3D SE-EPI signal intensities (relative to those of the BLK pulse) for the (c) BIR-4_dflt, (d) BIR-4_opt, (e) COMP3, and (f) OPT_100 pulses. The minimum T_R values were 136 ms for the BLK pulse, 227 ms for the BIR-4_dflt pulse, 233 ms for the BIR-4_opt pulse, 234 ms for the OPT_100 pulse and 235 ms for COMP3, indicating insignificant SAR differences among all but the BLK pulse. The BIR-4_dflt pulse results in modest signal increase (mean isocenter slice signal ratio of 1.15) while the BIR-4_opt, COMP3 and OPT_100 pulses result in much greater signal increases (mean isocenter slice signal ratios of 1.34, 1.34 and 1.41, respectively). At low B_1^+ values, signal ratios for the OPT_100 pulse are as high as 2.5, i.e., 250% of the signal obtained with the BLK pulse. While the BIR-4_opt pulse gives signal gains much larger than those of the BIR-4_dflt pulse, the COMP3 and OPT_100 pulses outperform both BIR-4 pulses in terms of insensitivity to B_0 variations. The OPT_100 pulse results in both the largest average and local signal increases while the COMP3 pulse has the advantage of minimizing signal loss in the highest B_1^+ regions. In conclusion, these latter two pulses, with subtle performance differences that may be advantageous to specific applications, provide excellent options for low-SAR refocusing at high field.

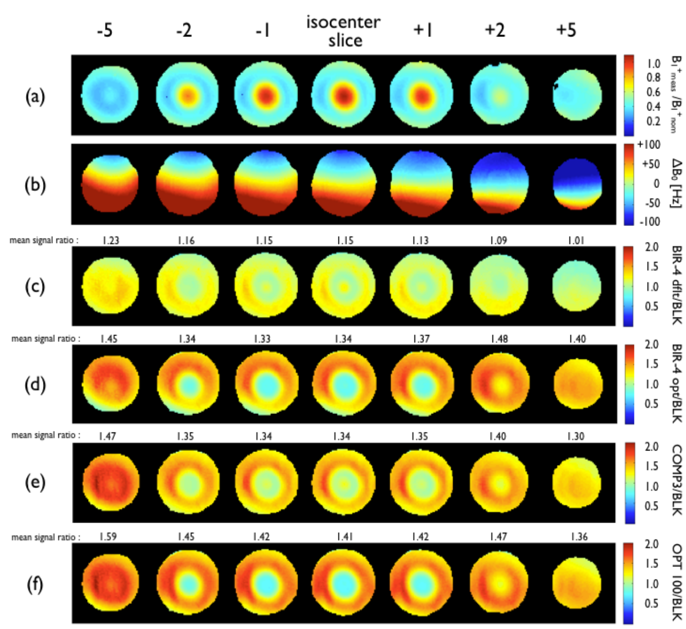

Fig.2: (a) B_1^+ and (b) ΔB_0 maps for 7 axial slices of an fBIRN phantom at 7 T. Ratio of signal from a 3D SE-EPI experiment with (c) BIR-4_dflt, (d) BIR-4_opt, (e) COMP3 and (f) OPT_100 refocusing pulses to the signal from the same experiment with the BLK refocusing pulse. Mean signal ratios are shown above each slice.

Acknowledgments: This work was supported by NIH grant number RO1EB000461. **References: [1]** M.H. Levitt, et. al., J. Magn. Reson. 43: 65 (1981). **[2]** R. S. Staewen et al., Invest. Radiol. 25: 559 (1990). **[3]** J. Moore et al., Proc. Intl. Soc.Mag. Reson. Med. 18 (2010). **[4]** M. Jankiewicz, et al., Proc. Intl. Soc. Mag. Reson. Med. 18 2859 (2010). **[5]** J. Moore et al., J. Magn. Reson., 205 (2010), 50-62.