Efficient Spatially-Selective Single-Slab 3D Turbo-Spin-Echo Imaging

J. P. Mugler, III[1], J. R. Brookeman[1]

[1]Radiology and Biomedical Engineering, University of Virginia, Charlottesville, VA, United States

Introduction: The echo-train efficiency (i.e., the number of echoes collected per unit time during the echo train) of single-slab 3D spin-echo-based imaging can be increased significantly by using short, non-spatially-selective RF pulses for both excitation and refocusing instead of conventional section-selective pulses [1]. However, this approach sacrifices the ability to perform slab selection and thus substantially limits the range of clinical applications. Previous studies have developed strategies to retain non-selective refocusing RF pulses in conjunction with spatial selectivity by using a two-dimensional excitation RF pulse [2,3], or selective RF pulses for excitation and (only) the first refocusing pulse, applied along orthogonal axes [3]. Neither of these approaches is suitable if variable-flip-angle refocusing RF pulses are used to achieve longer echo train durations [4], because the non-selective, non-180° refocusing pulses generate FIDs that result in artifacts of sharp signal transitions (i.e., "edges") which alias into the selected slab.

Our goal was to develop a simple and robust approach for spatially-selective single-slab 3D turbo-spin-echo (TSE) imaging that permits: (i) non-selective refocusing RF pulses to be used to achieve very short echo spacings and thus high echo-train efficiency; (ii) variable-flip-angle refocusing RF pulses to be used without associated artifacts; and (iii) a high-quality slab profile to be achieved thus minimizing the need to discard outer sections.

Sequence Design: The major features of our strategy are shown in Fig. 1. An optimized excitation RF pulse, generated using the public-domain MATPULSE program [5], yields a high-quality slab profile. This Shinnar-LeRoux type pulse has a duration of 10.24 ms, a time-bandwidth product of 28 ms-kHz, and pass- and reject-band ripples of 0.3% and 0.5%, respectively. Only the first echo spacing is extended to accommodate the duration of the excitation RF pulse; the remaining echo spacings are kept as short as possible considering the gradient performance, resolution and receiver bandwidth constraints. To account for the longer first echo spacing, the first refocusing RF pulse is required to be 180°, while the remaining refocusing RF pulses can have any desired values. If the first refocusing RF pulse were not 180°, stimulated echo components resulting from this pulse would not rephase at the desired echo time for echo spacings that are different than the first. Finally, to eliminate artifacts secondary to non-180° refocusing RF pulses, a two-step phase-cycling procedure is used wherein the phase of all refocusing RF pulses is incremented by 180° between excitations.

Methods: A single-slab 3D-TSE pulse sequence that incorporated the features described above was implemented on a 1.5-T whole-body scanner (Sonata; Siemens Medical Solutions). The refocusing RF-pulse flip angles required to achieve prescribed signal evolutions were calculated, based on the relaxation times for the selected reference tissue (brain gray matter) and the timing parameters for the pulse sequence, by using a rapid calculation algorithm that was integrated into the sequence [6]. The 740-ms prescribed signal evolution was an exponential decay (relative time constant 0.175) for the first 12% of the evolution, constant for the next 42% of the evolution, and an exponential decay for the remainder (relative time constant 0.290); the average refocusing RF-pulse flip angle was 60°. The effective echo time was set to the center of the prescribed signal evolution. This particular signal evolution shape has been previously demonstrated to produce contrast that is comparable to conventional T2-weighted spin-echo imaging [4]. Pulse sequence parameters included: TR/effective-TE, 3200/384 ms; matrix, 256 x 168 x 60; voxel size 1 x 1 x 1 mm; ESP, 4.4 ms; acquisition time, 6.4 min. Following preliminary testing in water phantoms, the 3D-TSE pulse sequence was used to obtain single-slab 3D image sets of the brains of healthy volunteers after obtaining informed consent.

Results: Representative images from the spatially-selective single-slab 3D-TSE pulse sequence are shown in Fig. 2. The sagittal and coronal reconstructions demonstrate the excellent slab profile achieved by using the optimized excitation RF pulse. None of the outer sections from the slab were discarded, yet essentially no aliasing in the section-select direction can be seen. No artifacts secondary to FIDs from the non-180° refocusing RF pulses are apparent in the axial image. (These would appear as distinct linear or curvilinear structures.)

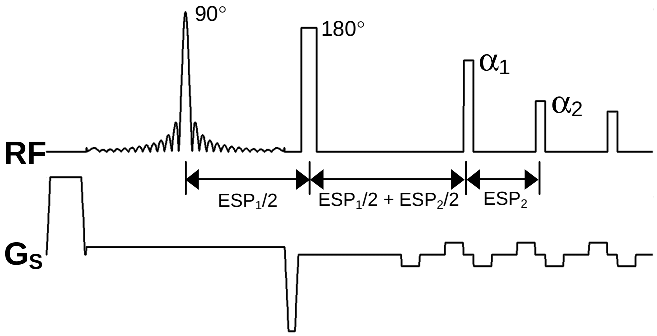

Fig. 1. Timing diagram of the section-select gradient (G_S) and RF pulses for the initial portion of a spatially-selective single-slab 3D pulse sequence. Magnitude RF waveforms are shown.

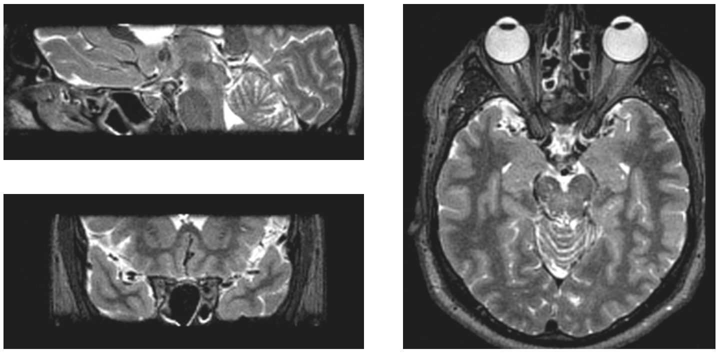

Fig. 2. Sagittal, coronal and axial brain images reconstructed from a spatially-selective single-slab 3D acquisition with isotropic 1-mm resolution.

Conclusions: We have developed a simple and robust approach for spatially-selective single-slab 3D-TSE imaging that provides a high-quality slab profile and that permits non-selective, variable-flip-angle refocusing RF pulses to be used to achieve very short echo spacings and long echo-train durations. This technique will make single-slab, variable-flip-angle 3D-TSE pulse sequences applicable for a much wider range of applications.

References:
1. Mugler JP et al. Radiology 2000; 216:891-899.
2. Luk-Pat GT et al. Magn Reson Med 1999; 42:762-771.
3. Mitsouras et al. Proc ISMRM 11 (2003); 968.
4. Mugler JP, Kiefer B, Brookeman JR. Proc ISMRM 8 (2000); 687.
5. Matson G, Elliott M. Version 2.4.
6. Mugler JP, Meyer H, Kiefer B. Proc ISMRM 11 (2003); 203.

Acknowledgements: Supported by National Institutes of Health grant NS-35142 and Siemens Medical Solutions.