

## Variable-flip angle 3D-turbo spin echo imaging utilizing spiral acquisitions

S. Fielden<sup>1</sup>, C. Meyer<sup>1,2</sup>, and J. P. Mugler, III<sup>1,2</sup>

<sup>1</sup>Biomedical Engineering, University of Virginia, Charlottesville, Virginia, United States, <sup>2</sup>Radiology, University of Virginia

**Introduction:** Shaping the signal evolution by varying the refocusing RF-pulse amplitudes in turbo-spin-echo (TSE)-type sequences has allowed the use of very long echo trains [1, 2], which have proven useful for  $T_2$ -weighted single-slab 3D-TSE imaging in a variety of applications. However, 3D  $T_2$ -weighted imaging remains time consuming when the number of 3D phase encodes is large, with scan times on the order of 5-10 minutes. Spiral acquisition gradients cover  $k$ -space more efficiently than the traditional, Cartesian approach, and thus provide an attractive method by which shortened scan times can be achieved. In addition, the low sensitivity of spiral acquisitions to flow and motion may be valuable for applications in the chest or abdomen. The purpose of this work was to implement and perform a preliminary evaluation of variable-flip-angle 3D-TSE imaging using spiral  $k$ -space sampling.

**Methods:** A commercial version of a variable-flip-angle 3D TSE pulse sequence (SPACE) was modified to utilize spiral readouts in order to reduce acquisition time (Fig. 1). The RF-pulse series was calculated for gray matter in the manner described in [3]. The sequence uses the same ordering scheme as the spiral refocused-TSE sequence [4] in which each excitation acquires a single interleaved from every 3D phase encode, with the number of excitations equal to the number of interleaves, and the echo train length equal to the number of 3D phase encodes. The spiral 3D-TSE method was tested for  $T_2$ -weighted brain imaging in healthy volunteers, and compared to the standard SPACE pulse sequence. Sequence parameters for the spiral 3D TSE were: field strength: 3T (Trio, Siemens Medical Solutions), echo train duration: 792 ms (echo train length: 127), constant-density spiral duration: 2.4 ms (echo spacing: 6.24 ms), TR: 3000 ms, effective TE: 396 ms. The spiral waveform was centered in the inter-pulse period, rather than beginning at the spin-echo, in order to improve acquisition efficiency. Informed consent was obtained prior to imaging.

**Results:** Figure 2 shows slices mid-way through the image volume in each of three orthogonal directions. The resulting resolution, based on full-width-half-maximum of the spiral point-spread-function, was  $1.8 \times 1.8 \times 1.5 \text{ mm}^3$ , and the acquisition time was 2.5 minutes (no parallel-imaging acceleration). Image signal intensity and contrast were similar to those obtained with a comparable Cartesian variable-flip-angle 3D-TSE sequence, which had an acquisition time of 6.4 minutes.

**Discussion:** The in-plane resolution of the Cartesian 3D-TSE sequence used in this study can be increased by lengthening the echo train or utilizing partial-Fourier techniques, while echo spacing and the number of excitations remains the same. Since the ordering of the spiral TSE sequence differs from its Cartesian counterpart, increasing the in-plane resolution requires some combination of increasing the echo spacing and/or increasing the number of excitations (interleaves). Longer echo spacings in TSE-type sequences are known to reduce the signal intensity of fat and certain other species (e.g., hemorrhage). However, aside from this, the potential effect of relatively long echo spacings on white/gray matter contrast in single-slab 3D-TSE imaging is currently unknown and is a matter of future investigation. In our case, echo spacings of approximately double that of the Cartesian sequence had little impact on image contrast.

**Conclusion:** Very long spiral spin-echo trains with prescribed signal evolutions are a promising method for reducing the acquisition time of single-slab 3D-TSE imaging. Substantial additional reduction in acquisition time is likely possible by combining this approach with (slice) partial-Fourier and parallel imaging techniques.

**References:** [1] Mugler, et al. ISMRM (2000) #687. [2] Busse, et al. MRM (2006) 55; 1030-7. [3] Mugler, et al. ISMRM (2003) #203. [4] Fielden, et al. ISMRM (2010) #3788.

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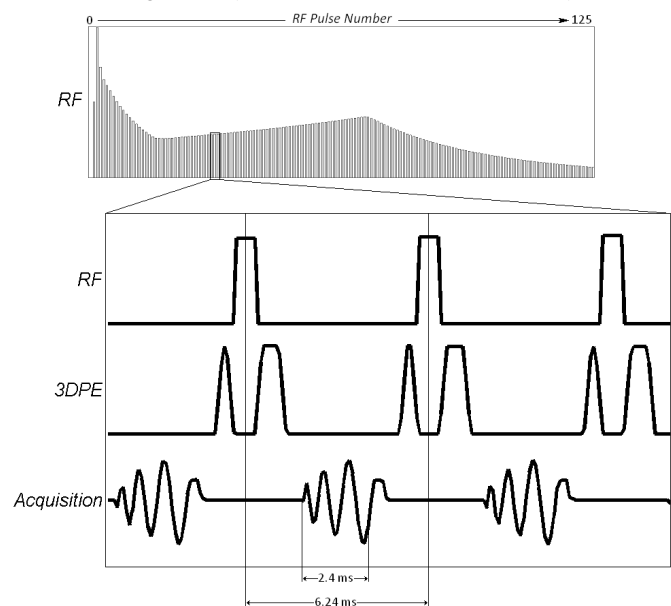


Figure 1. RF-pulse variable-flip-angle series and pulse-sequence timing for the 127-echo 3D images shown in Fig. 2

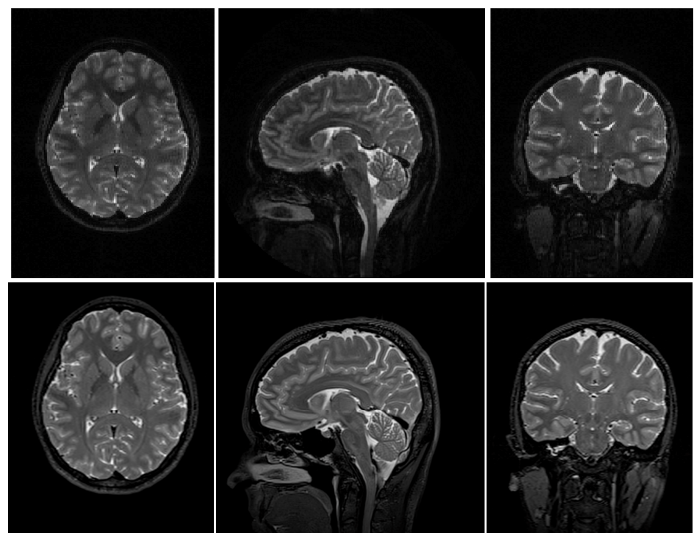


Figure 2. Transverse, sagittal, and coronal slices reconstructed from the 3D image volume. Top row: spiral, bottom row: Cartesian.