

Radial Single-slab 3D Turbo Spin Echo (SPACE)

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Target audience: Imaging scientists interested in 3D, fast/turbo spin-echo, or non-Cartesian sampling-trajectory MR acquisition methods.

Introduction & Purpose: Optimized, single-slab, 3D fast/turbo spin-echo (FSE/TSE) imaging (e.g., CUBE [GE], SPACE [Siemens], VISTA [Philips]) has recently gained popularity for a variety of clinical applications. While currently-available commercial implementations use conventional Cartesian (rectilinear) sampling of k space, certain applications may benefit from the favorable properties of non-Cartesian k -space trajectories. Several previous research studies using FSE/TSE have shown potential benefits for radial or spiral trajectories, particularly for reducing sensitivity to motion [e.g., 1,2]. The purpose of our current work was to incorporate radial k -space sampling into optimized, single-slab, 3D FSE/TSE imaging, and to perform a preliminary evaluation of imaging performance. Our long-term goal is to develop a single-slab 3D FSE/TSE method that has substantially reduced sensitivity to motion relative to existing rectilinear-based techniques. Compared to previous research in this area, an open question is whether acceptable image quality can be achieved when radial k -space trajectories are combined with the very long spin-echo trains and variable-flip-angle refocusing RF pulses used in state-of-the-art single-slab 3D FSE/TSE techniques.

Methods: A commercial version of single-slab 3D TSE (SPACE) was modified to support radial trajectories. Spatial-frequency space was sampled using the established "stack of stars" approach, wherein planes of k space are collected with radial trajectories and conventional phase-encoding is used in the 3rd direction to map the signal evolution along the echo train into k space to achieve the desired image-contrast properties. Ideally, this means that a given echo number in the spin-echo train contributes data only to a single plane of k space (over a range of radial angles). However, to permit more efficient use of the available data, we used a flexible reordering scheme for 3D FSE/TSE [3,4] which allowed data from a small range of echo numbers to contribute to a given plane of k space. Acquisition of correction data for aligning k -space centers among trajectory angles was integrated into the pulse sequence. However, for this prototype implementation, we used data from one echo position to correct all echoes; this is a processing/reconstruction issue which will be fixed in future implementations. After initial testing using water phantoms, the radial SPACE sequence was used to acquire 3D T2-weighted image sets in healthy human volunteers at either 1.5T (Aera, Siemens) or 3T (Skyra, Siemens). As an initial assessment of sensitivity to motion, whole-brain T2-weighted image sets were acquired using both rectilinear and radial SPACE as the subject tilted his head slightly to the left or to the right throughout the acquisition (50% in neutral position, 25% tilted to left and 25% tilted to right). Informed consent was obtained prior to imaging.

Results: Three contiguous axial images of the brain of a healthy volunteer are shown in Fig. 1 (3T, TR/TE_{eff} 2800/413 ms [contrast equivalent TE ~100 ms], 300 radial views, 194 echoes, variable-flip angle refocusing RF pulses, voxel volume 1 x 1 x 1.2 mm³, acquisition time 5.5 min). The images show the expected T2-weighted contrast and no significant image artifacts. Figure 2a-c shows sagittal, coronal and axial images of the brain of a healthy volunteer reconstructed from an acquisition with 1.2-mm isotropic resolution (3T, TR/TE_{eff} 2800/412 ms [contrast equivalent TE ~100 ms], 300 radial views, 194 echoes, variable-flip angle refocusing RF pulses, acquisition time 9 min). Again, the images demonstrate the expected T2-weighted contrast and generally good image quality. In both phantom and human images, some residual streaking artifacts were seen, as illustrated in Fig. 2d. We believe that these artifacts can be suppressed through improved echo alignment as achieved by using echo-number-specific correction factors. For the head-motion study, the rectilinear acquisition showed marked artifacts propagating through much of the brain (Fig. 3a, e.g., arrows) whereas only a few minor ringing artifacts were seen in the radial acquisition (Fig. 3b), confirming the expected substantially reduced sensitivity to motion for the radial acquisition.

Conclusions: We have demonstrated that good image quality can be obtained when radial k -space sampling is combined with the very long spin-echo trains and variable-flip-angle refocusing RF pulses used in state-of-the-art single-slab 3D FSE/TSE techniques. We anticipate that improvements in echo alignment will further improve image quality, making it comparable to that achieved with conventional rectilinear trajectories, and thus suitable for clinical application. By implementing parallel-imaging and/or compressed-sensing strategies to offset the inherent inefficiency of radial sampling, we expect to obtain a robust, clinically-applicable method of 3D spin-echo-based imaging with substantially reduced sensitivity to motion.

References: 1. Rasche V et al. Magn Reson Med 1994; 32:629. 2. Block W et al. Magn Reson Med 1997; 37:582. 3. Busse RF et al. Magn Reson Med 2008; 60:640. 4. Li G et al. Proc ISMRM 17 (2009); 2623.

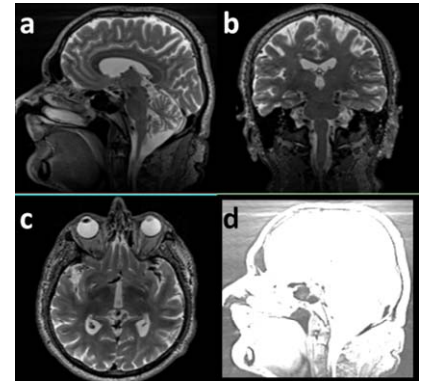


Figure 2. (a) Sagittal, (b) coronal and (c) axial T2-weighted images reconstructed from a 3D radial SPACE acquisition in a healthy volunteer. (d) Image (a) is shown with different window, level settings to illustrate residual streaking artifacts.

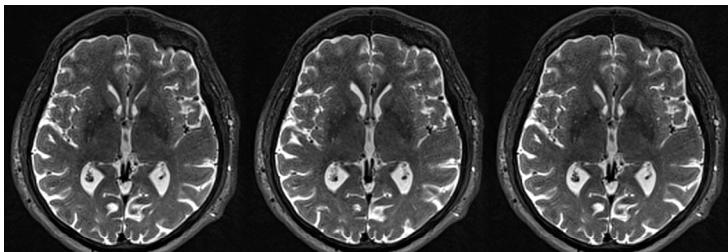


Figure 1. Contiguous T2-weighted axial images of the brain from a 3D radial SPACE acquisition in a healthy volunteer.

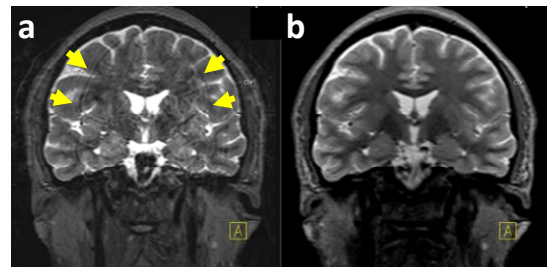


Figure 3. Comparison of (a) rectilinear SPACE to (b) radial SPACE in the presence of rocking head motion.