3D Turbo-Spin-Echo Imaging with up to 1000 Echoes per Excitation: From Faster Acquisitions to Echo-Volumar Imaging

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

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

Introduction: Tissue-specific prescribed signal evolutions, achieved by using refocusing RF pulses with variable flip angles, have been used to decrease the acquisition time for single-slab 3D turbo/fast spin-echo (TSE) imaging by substantially increasing the usable echo-train duration compared to that achieved with 180° refocusing RF pulses [1]. With this technique, an echo train duration of approximately one second was demonstrated that yielded image contrast in the brain similar to that achieved using conventional 2D T2-weighted spin-echo or TSE pulse sequences [2]. Although previous studies have acquired at most one plane of the three-dimensional *k* space following each excitation RF pulse, it is in principle possible to acquire enough echoes during such long echo-train durations to encode two or more complete planes of *k* space each excitation, thus providing even faster 3D spin-echo-based acquisitions. The purpose of this study was to explore the potential of such "multi-*k*-space plane" acquisitions.

Methods: A single-slab 3D-TSE sequence 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 (e.g., brain gray matter) and the timing parameters for the pulse sequence, by using a rapid calculation algorithm that was integrated into the sequence [3]. To acquire multiple *k*-space planes during a single spin-echo train, the 3D phase-encoding gradient was incremented over all strengths for that excitation before incrementing the 2D phase-encoding gradient to its next value. Following preliminary testing in water phantoms, the TSE pulse-sequence configurations described below were used to obtain single-slab 3D image sets of the brains of healthy volunteers after obtaining informed consent.

Three multi-*k*-space plane sequence configurations were evaluated: **(1):** Whole-brain 3D-TSE imaging with contrast comparable to T2-weighted spin-echo imaging and 1-mm isotropic resolution in 10 minutes was demonstrated in reference [1]. Our first test configuration was a 2 *k*-space plane version of this technique that acquired 330 echoes per excitation RF pulse during a 950-ms prescribed signal evolution, yielding 1-mm isotropic resolution of the whole brain in 4.9 min. Other parameters included: TR/effective-TE, 3200/480 ms; matrix, 256 x 165 x 208; 7/8 partial Fourier in the 3D direction; ESP, 2.9 ms; prescribed signal evolution: exponential decay, constant, exponential decay for gray matter (see [2] for details). (Effective-TE denotes when the center of *k* space is collected. However, since the prescribed signal evolution contains a substantial contribution from magnetization stored along the z-axis for a portion of the evolution, the image appearance is much different than that which would be obtained for an equivalent TE in a conventional spin-echo image.) **(2):** A pseudosteady state [4] signal evolution with a terminal flip angle of 140° was used in a 3 *k*-space plane sequence that acquired 531 echoes per excitation RF pulse during a 2600-ms signal evolution. This technique was designed to achieve bright CSF for imaging the internal auditory canal (IAC). Other parameters were: TR/effective-TE, 8000/1310 ms; matrix, 256 x 177 x 36; voxel size, 0.7 x 0.7 x 1.0 mm; ESP, 4.88 ms; acquisition time, 3.2 min. **(3):** Finally, our third test configuration used an extended version (1660 ms) of the prescribed signal evolution from configuration (1) that acquired 1056 echoes following the excitation RF pulse – enough echoes to completely encode a 64 x 33 x 32 3D data set using a single excitation, i.e., TSE-based echo-volumar [5] imaging. Other parameters were: effective-TE, 830 ms; voxel size, 5 x 5 x 5-6 mm; ESP, 1.58 ms.

Results & Discussion: Representative images from the three sequence configurations are shown in Figs. 1-4. Figure 1 shows sagittal, coronal and axial reconstructions from the 1-mm isotropic 3D data set of the whole brain (configuration 1). The image quality was essentially identical to that from the 10-minute version [1], except for decreased SNR secondary to lower signal levels with the longer prescribed signal evolution. Figure 2 shows an axial section from the IAC sequence (configuration 2), clearly depicting the acoustic nerves with high SNR. Sagittal, coronal and axial reconstructions of a spherical water phantom, obtained following a *single* excitation RF pulse (configuration 3), are shown in Fig. 3. Images of the human head acquired by using the 1056-echo sequence (configuration 3) are shown in Fig. 4. Due to the presence of fat, which has a short T1, a 2-step phase-cycling scheme was required to suppress artifacts caused by FIDs from fat generated by the low-flip-angle refocusing RF pulses as fat relaxed during the long echo train. (Nonetheless, the complete volume was encoded with each of the two excitations. We are currently optimizing the spoiling scheme to suppress these FID artifacts without the need for two excitations.)

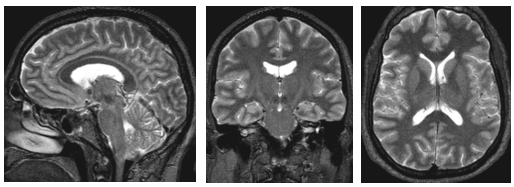

Fig. 1. Sagittal, coronal and axial brain images reconstructed from a 330-echo, 4.9-min. 3D acquisition with isotropic 1-mm resolution.

Fig. 3. Sagittal, coronal and axial phantom images reconstructed from a single-shot (echo-volumar) 1.7-sec. 3D acquisition with 1056 echoes.

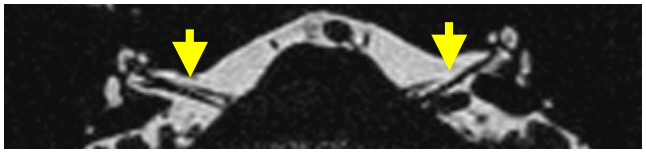

Fig. 2. Axial brain image depicting the acoustic nerves (arrows). Three *k*-space planes (531 echoes) were acquired each excitation.

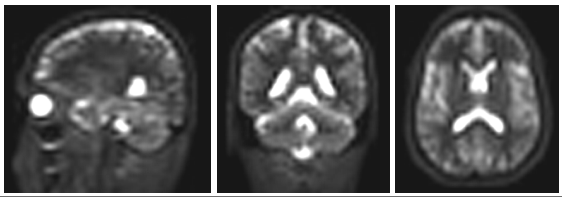

Fig. 4. Sagittal, coronal and axial brain images from a phase-cycled (2-shots x 1.7 sec.) version of the 3D acquisition with 1056 echoes.

Conclusions: By taking advantage of the long echo-train durations that can be achieved with prescribed signal evolutions, the acquisition of multiple planes of *k*-space data following each excitation RF pulse permits further substantial reductions in the acquisition times for 3D spin-echo-based imaging. Albeit with coarse spatial resolution, even echo-volumar imaging is possible. By combining this strategy with parallel imaging methods and increased SNR from high-field scanners, it seems probable that further substantial reductions in the acquisition times for 3D imaging will be possible in the future.

References: 1. Mugler JP, Kiefer B, Brookeman JR. Proc ISMRM 8 (2000); 687. 2. Mugler JP, Brookeman JR. Proc ISMRM 11 (2003); 970. 3. Mugler JP, Meyer H, Kiefer B. Proc ISMRM 11 (2003) 203. 4. Alsop DC. Magn Reson Med 1997; 37:176-184. 5. Mansfield P, Howseman AM, Ordidge RJ. J Phys E: Sci Instrum 1989; 22:324-330.

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