

High-Resolution, Multi-Contrast 3D Imaging of the Brain in 15 Minutes

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Introduction: It is well established that 3D acquisitions with high, isotropic spatial resolution offer distinct advantages for evaluating complex structures such as the brain. Despite this fact, high-resolution 3D imaging is often not used for routine assessment of the brain, and is typically relegated to a limited specialty role. The primary reasons for this are twofold: (1) the acquisition times for high-resolution 3D imaging have remained long relative to those for 2D turbo/fast spin-echo (TSE/FSE) imaging, and (2) only techniques for T1-weighted contrast have been widely available. However, recent advances in pulse-sequence design, multi-coil imaging strategies and scanner hardware present the opportunity for much faster acquisitions and more-flexible contrast behavior. As an example of the potential for such techniques, the goal of this work was to implement a protocol for obtaining high-resolution 3D image sets of the whole brain with T1-weighted, T2-weighted and dark-fluid (FLAIR) contrast in a total acquisition time of only 15 minutes. The 3D-TSE pulse sequences used for T2-weighted and FLAIR contrast feature a novel strategy for accelerating the acquisition that combines very long spin-echo trains with parallel imaging along the echo train to collect multiple complete *k*-space planes following each excitation RF pulse.

Methods: Studies were performed at 3 Tesla (TRIO, Siemens Medical Solutions) with an 8-channel head RF coil (MRI Devices Corp.) to obtain high, intrinsic SNR, which was traded for a decreased acquisition time by using a parallel-imaging strategy (GRAPPA). T1-weighted imaging was performed by using the 3D MP-RAGE method; the timing parameters and flip angle were optimized in human subjects to yield maximum gray, white contrast at 3 Tesla. A parallel-imaging acceleration factor of 2 was applied along the phase-encoding direction for which the gradient was varied between applications of the inversion RF pulse. Other pulse-sequence parameters included: TR/TE/TI, 6.7/2.9/900 ms; time between inversion pulses, 2250 ms; flip angle, 9°; matrix, 256 x 211 x 160; voxel size, 1.0 x 1.1 x 1.1 mm; 7/8 partial Fourier in both phase-encoding directions; acquisition time, 3.9 min.

T2-weighted and FLAIR imaging was performed by using a single-slab 3D-TSE pulse sequence that utilized a tissue-specific prescribed signal evolution, achieved by using refocusing RF pulses with variable flip angles. This approach permits the acquisition time to be decreased by substantially increasing the usable echo-train duration compared to that achieved with 180° refocusing RF pulses [1,2]. Parallel imaging (acceleration factor 2) was used along the in-plane phase-encoding direction to reduce the required number of phase-encoding views to slightly more than one-half of the corresponding matrix size. By using a very long echo-train duration (T2-weighted, 860 ms; FLAIR, 790 ms) and a short echo spacing (T2-weighted, 3.3 ms; FLAIR, 3.2 ms), more than 200 echoes could be acquired (T2-weighted, 262 echoes; FLAIR, 246 echoes) following each excitation RF pulse. Due to the reduction in phase-encoding views secondary to parallel imaging, this large number of echoes permitted two complete planes of *k* space to be collected for each excitation RF pulse, thus further reducing the acquisition time. Parameters for the T2-weighted acquisition included: TR/effective-TE, 3200/430 ms; matrix, 320 x 238 x 192; 7/8 partial Fourier in the slice-encoding direction; acquisition time, 4.4 min. Parameters for the FLAIR acquisition included: TR/effective-TE/TI, 6000/400/2100 ms; matrix, 256 x 222 x 192; 7/8 partial Fourier in the slice-encoding direction; acquisition time, 7.1 min. (A variable-flip-angle, prescribed signal evolution with the aforementioned parameters produces contrast that is comparable to conventional T2-weighted spin-echo imaging, despite the very long effective-TE [1].) For both 3D-TSE sequences the voxel size was 0.9 x 0.9 x 0.9 mm. All studies were performed in healthy volunteers after obtaining informed written consent.

Results: Representative images from the T1-weighted, T2-weighted and FLAIR acquisitions are shown in Figures 1, 2 and 3, respectively. (The image sets in Figures 2 and 3 were acquired from the same subject.) Each figure shows sagittal, coronal and axial reconstructions from the respective high-resolution, 3D data sets of the whole brain. No significant artifacts from the parallel-imaging process, or from the acquisition of two planes of *k*-space data following each excitation RF pulse, were observed in any of the image sets. For the FLAIR image sets, the single-slab nature of the acquisition suppressed pulsation artifacts from CSF and blood flow throughout the brain.

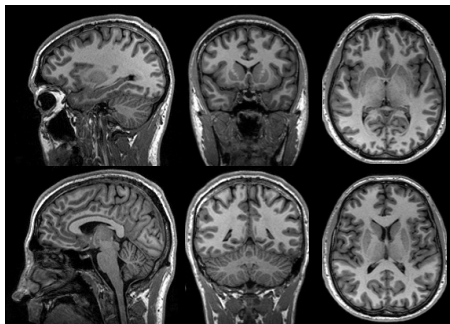


Fig. 1. T1-weighted sagittal, coronal and axial brain images reconstructed from a 3.9-min. 3D MP-RAGE acquisition with 1.0 x 1.1 x 1.1 mm spatial resolution.

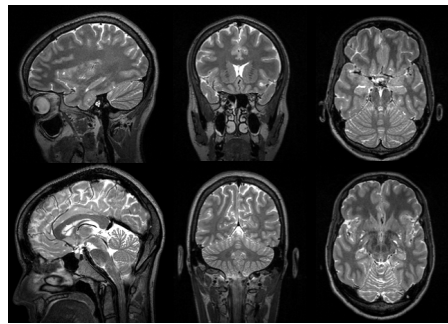


Fig. 2. T2-weighted sagittal, coronal and axial brain images reconstructed from a 4.4-min. single-slab 3D-TSE acquisition with isotropic 0.9-mm spatial resolution.

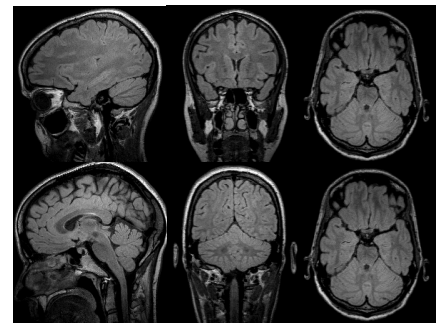


Fig. 3. FLAIR sagittal, coronal and axial brain images reconstructed from a 7.1-min. single-slab 3D-TSE acquisition with isotropic 0.9-mm spatial resolution.

Conclusions: By combining advances in pulse-sequence design, multi-coil imaging strategies and scanner hardware, we have demonstrated high-resolution 3D techniques with much shorter acquisition times and more-flexible contrast behavior than those currently available. As a specific example, we implemented a protocol that permits T1-weighted, T2-weighted and FLAIR imaging of the whole brain with high (≤ 1 mm) isotropic spatial resolution in a total acquisition time of 15.4 minutes. The short acquisition times for such techniques may make them useful not only for specialized applications, such as brain morphometry or therapy monitoring, but also for routine clinical assessment of the brain.

References: 1. Mugler JP, Kiefer B, Brookeman JR. Proc ISMRM 8 (2000); 687.
2. Mugler JP, Meyer H, Kiefer B. Proc ISMRM 11 (2003) 203.

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