Echo-Planar Imaging with Multiple Echo Trains in a Single-Shot Using Stimulated Echoes

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In the presence of off-resonance effects like susceptibility differences or magnetic field inhomogeneities echo-planar imaging (EPI) [1] suffers from geometric distortions due to the accumulation of phase errors along the echo train. In (multi-shot) segmented EPI [2] these artifacts are reduced because only a part of k-space is acquired within each shot and the echo train can be shortened accordingly. However, a reliable signal phase from shot to shot is required that hampers the applicability to diffusion-weighted imaging with its high sensitivity to physiologic motion. Here, an alternative approach is presented that acquires multiple short echo trains within a single shot using stimulated echoes.

Methods

The basic pulse sequence (Fig. 1) involves an RF pulse to flip back the prepared, e.g. diffusion-weighted, magnetization to the longitudinal direction. A segment of k-space is acquired by applying a readout RF pulse to the stored longitudinal magnetization followed by a gradient echo train. To maintain longitudinal magnetization for the subsequent segments these RF excitations (except for the last one) must have flip angles below 90°. Prior to the flip back a dephasing gradient (shaded) is applied that spreads the magnetization uniformly in the transverse plane and ensures a flip-back effect that is independent of the phase of the prepared magnetization (that may be unknown, e.g. due to diffusion-weighted imaging). To compensate this dephasing, a rephasing gradient (shaded) is required prior to each echo train that also spoils relaxed, non-prepared magnetization. Due to these gradients, the signal generated by the RF pulses is effectively a stimulated echo. Thus, the method is similar to the GRASTE imaging technique [3].
Measurements were performed on a 3T whole-body MR system (Siemens Magnetom Trio) using a standard eight-channel head coil. Written informed consent was obtained from all volunteers prior to the examination. Images of single-shot spin-echo EPI (140ms per section), three-shot segmented spin-echo EPI (3x80ms), and EPI with multiple echo trains in a single shot (three echo trains, 224ms) were obtained with a resolution of 2x2x5 mm³ and a field-of-view of 192x256 mm^2. All acquisitions involved fat saturation and reference lines for phase-correction. The multiple echo trains in a single shot were acquired with different flip angles of the readout RF (35°, 45°, 90°) that were chosen to obtain similar signal amplitudes for all echo trains and fully exploit the stored magnetization.

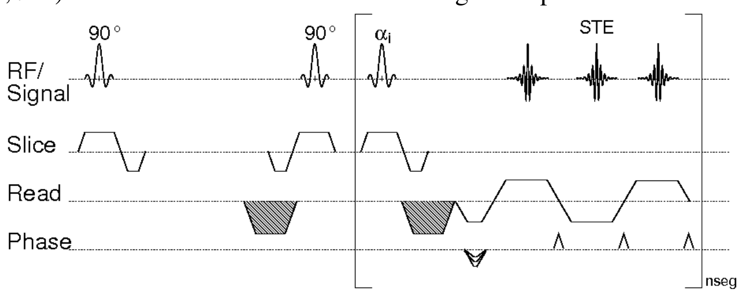

Figure 1: Basic pulse sequence for EPI with multiple echo trains in a single shot using stimulated echoes (three echoes per echo train).

Results and Discussion

Figures 2 shows two sections of a healthy volunteer. Segmented EPI and EPI with multiple echo trains in a single-shot considerably reduce the geometric distortions present in standard EPI. Due to the usage of stimulated echoes and the need for lower flip angles of the readout RF excitations, the signal-to-noise ratio is reduced for EPI with multiple echo trains compared to segmented EPI that involves three acquisitions. However, EPI with multiple echo trains in a single shot is insensitive to shot-to-shot phase variations and motion-related phase distortions induced during the preparation period. It may therefore find applications in diffusion-weighted imaging.

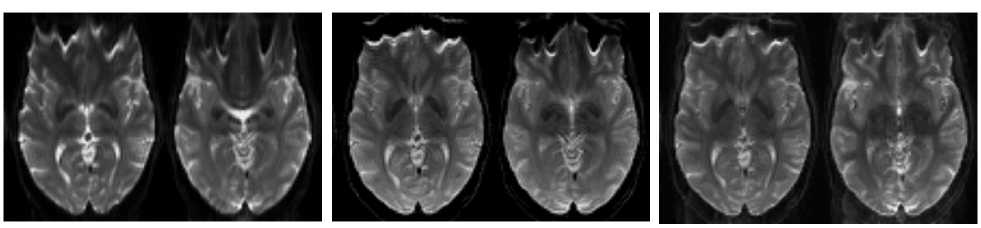

Figure 2: MR images obtained with single-shot EPI (left), multi-shot segmented EPI (middle), and EPI with multiple echo trains in a single shot using stimulated echoes (right).

References

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[3] Finsterbusch J et al, Magn Reson Med 55, 455 (2006)