Investigation and Continuous Correction of Motion during Turbo Spin Echo Sequences

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Introduction: Turbo spin echo (TSE) sequences [1] are useful for rapid, high-resolution structural imaging. However, even small movements from cooperative subjects during acquisition can cause severe artifacts, due to the motion sensitivity of this technique. It has been shown that prospective motion correction [2] can compensate for motion during imaging. This work investigates the effects of motion TSE sequences and the influence of two types of prospective motion correction on image quality.

Methods: All experiments were performed on a 3 T Magnetom Trio (Siemens Healthcare, Germany) using an optical in-bore system [3] to track head position. Two turbo spin echo sequences (2D TSE and the 3D TSE variant 'SPACE' [4]) were modified to perform prospective motion correction (Fig.1). In a first step, motion correction was applied once per TR. Then, to correct for motion during the echo train, additional position updates were introduced before each refocusing pulse without interruption of the sequence timing (as previously done for DWI [5]). Phantom experiments were performed to investigate the influence of motion during and between echo trains. To achieve this, different motion artifacts were reproduced using the ability of the motion correction technique to simulate relative motion between scanner and phantom [6]. Both sequences were tested *in vivo*. All parameters used are shown in Tab 1. For the SPACE sequence, a GRAPPA acceleration factor of 2 was used. The volunteers were instructed to perform either small position changes in the range of one millimeter (protocol 2 and 4) or to stay as still as possible (protocol 3).

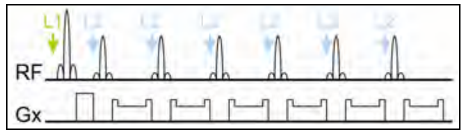

Fig.1: Diagram showing parts of a TSE sequence and the position updates implemented. The first level (L1) updates before excitation, the second level (L2) corrects for motion during the echo train.

Protocol	TR ms	TE ms	Turbo factor	Voxel size mm³	TA min
1) 2D Phantom	1000	90	21	0.4×0.4×3	0:28
2) 2D *in vivo*	6000	90	21	0.4×0.4×3	2:08
3) 2D *in vivo*	6500	87	21	0.3×0.3×2	9:53
4) 3D *in vivo*	4000	329	203	0.5 iso	7:46

Tab. 1: Sequence parameters used for phantom (Fig.2), and *in vivo* measurements (Figs. 3 and 4).

Results: Figure 2 shows results from the phantom experiments simulating motion during (A, B) and between (C, D) echo trains in two degrees of freedom. In Fig. 3 the results of two 2D TSE experiments are presented. The first experiment using protocol 2 included three measurements (A, B, and C) with small constant motion (~0.2 mm, ~0.1 deg). The second experiment using protocol 3 (high resolution) for two acquisitions (D and E) with no deliberate motion (slow drifts of ~2 mm, ~2 deg). Selected slices from the SPACE measurements are presented in Fig. 4. First a measurement (A) with no deliberate motion is displayed for comparison. In the following measurements the volunteer was performing small constant movements (~2 mm, ~2 deg). First, an uncorrected image is shown (B). The following two images show the results of performing correction once per excitation (C) and a continuous motion correction during the echo train (D).

Discussion: The phantom experiments show that the effect of motion during the readout train is not negligible when faster motion occurs or a higher turbo factor is used. *In vivo* experiments support these first results. In the standard 2D protocol the correction of single echo trains reduces inconsistencies of the acquired data and the resulting artifacts. Further motion correction seems not to be necessary in the case of short echo trains. However, this first correction already leads to great improvements in image quality even when used on extremely cooperative volunteers.

When longer readouts are used (e.g. SPACE), a correction once per excitation is not sufficient and the continuous correction of the echo train shows further improvement. Even with continuous head motion during the whole examination it becomes possible to acquire images comparable to those of a patient staying still. In conclusion, this work shows that prospective motion correction can improve results of high resolution TSE imaging even in cooperative volunteers while preserving the desired sequence timing.

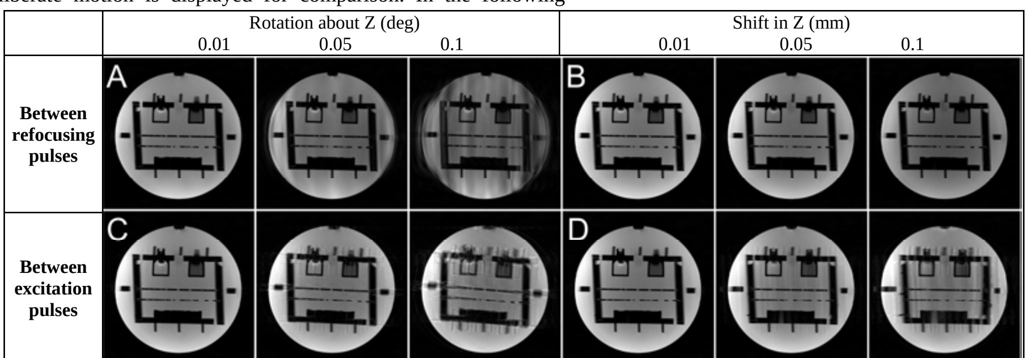

Fig. 2: Phantom experiments simulating motion during acquisition (transversal slices). The images show artifacts resulting from (A) rotations about Z and (B) shifts in Z during the echo train and (C) rotations about Z and (D) shifts in Z between the echo trains.

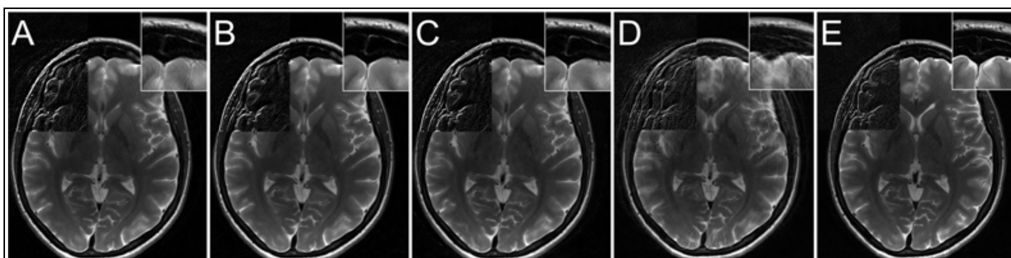

Fig. 3: Images acquired with protocol 2 including small movements (A, B, and C), and protocol 3 with no intended motion. The comparison of uncorrected images (A, D) with acquisitions corrected once per excitation (B, E) show the necessity to perform motion correction and the ability of the technique to improve even images from extremely cooperative volunteers. Continuous motion correction (C) seems not to have much impact as long only small motion (e.g. ~0.2 mm, ~0.1 deg) occurs during short echo trains.

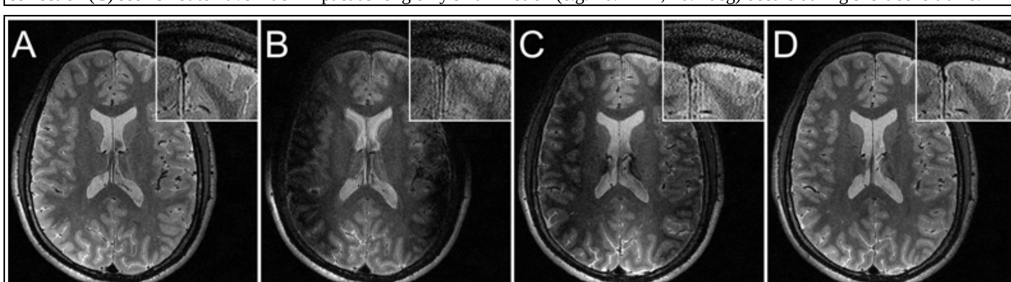

Fig. 4: Images acquired with protocol 4: (A) was performed without motion. During the following measurements head motion was performed and was uncorrected (B), corrected each TR (C) and corrected continuously (D). Continuous prospective motion correction (D) shows further improvement over less frequent updates and results in images comparable to these acquired without motion.

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References: [1] Hennig et al., MRM 1986; 3(6):823–833. [2] Zaitsev et al., Neuroimage, 31(3):1038-1050, 2006. [3] Armstrong et al., ISMRM, #5035, 2010. [4] Mugler et al., ISMRM, 2000. [5] Herbst et al., ISMRM, #170, 2011. [6] Herbst et al., ESMRMB, #540, 2011.