Preservation of Magnetization Coherence Conditions for Multi RF Pulse Sequences during Motion Correction: Translational Motion

Matthias Weigel [1,2], Oliver Bieri [1], Maxim Zaitsev [2], Michael Herbst [2]

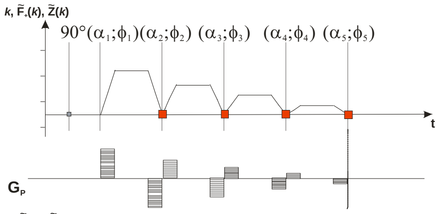
[1] Radiological Physics, University of Basel Hospital, Basel, Switzerland
[2] Medical Physics, Dept. of Radiology, University Medical Center Freiburg, Freiburg, Germany

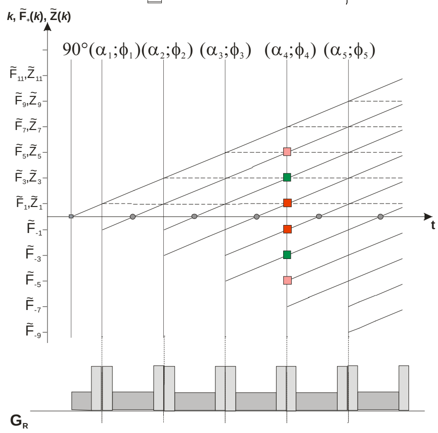
Purpose

Optical motion tracking concepts have demonstrated great value in mitigating motion related artifacts in MRI **{1}**. Translations of the object do not need dynamic gradient adaptations. However, motion also causes phase changes of the magnetization. Multi RF pulse sequences such as the TSE rely on specific phase coherence relations, thus, continuous preservation of these phase relations is of great importance. In the following, the effect of and correction for translational motion is investigated.

Methods

Multi RF pulse sequences are usually investigated best within the extended phase graph (EPG) concept **{2,3}**. Here, a TSE sequence and its basic spatial encoding are analyzed. A TSE sequence is based on the Carr-Purcell-Meiboom-Gill scheme that (ideally) ensures permanent in-phase refocusing conditions {4}: The magnetization and the refocusing RF pulses have the same phase. Thus, the aim is to preserve this in the presence of translational motion. However, translational motion affects longitudinal and transverse magnetization states differently **{3,5}:** The respective phase shifts are $\phi_T = \frac{\mathbf{k}^{(1)}+\mathbf{k}^{(2)}}{2}\mathbf{v}\,\tau$ and $\phi_L = \mathbf{k}^{(1)}\mathbf{v}\,\tau$ [1].





Results

The basic idea is to correct the phase ϕ_i of refocusing RF pulse #i with the particular phase acquired due to motion in each refocusing interval. However, as can be seen from Eq. [1], the phase accrual is directly proportional to the dephasing order $|\mathbf{k}|$ of the magnetization, besides its type (longitudinal or transverse). Since the suggested solution of adapting the RF pulse phase ϕ_i offers one degree of freedom only, it can be therefore deduced that, generally, a 'perfect' phase adaptation for translational motion cannot be realized in a TSE sequence scenario.

Fig. 1 demonstrates an EPG-like representation along the phase encoding direction G_P. Adding up phase terms ϕ_T in small intervals τ leads to the overall RF phase increment necessary. The rewinding of the phase encoding gradient per echo spacing (Fig. 1) leads to the favorable situation of one transverse magnetization component only (red dots). Thus, translational motion in the phase encoding can be completely corrected for, if the correction interval is sufficiently short.

Fig. 2 demonstrates an EPG representation for the read encoding direction G_R. Of considerable importance are the different magnetization pathways evolving. In a TSE sequence without motion all pathways interfere constructively (signal adds up). Hence, with motion, the condition is that all pathways of the same dephasing order as denoted at RF pulse #3 should ideally add constructively (example in Fig. 2, pairwise colors), which leads to the final condition of phase coherence between all dephasing states. Due to the linear increase of phase accrual with dephasing order $|\mathbf{k}|$ (shifted harmonic modulation phase pattern), which is different for transverse and longitudinal magnetization (Eq. [1]), one can only select one magnetization component that will be fully phase corrected. The best is to choose the dominant transverse magnetization component of the lowest dephasing order (F_{-1} to F_1). This corresponds to preserving the primary spin echo component.

The depicted effect becomes more important for low flip angle TSE sequences with long echo trains such as SPACE. For a standard TSE180°, the RF phase adaptation concept also works perfectly, similar to the phase encoding direction: Only one pathway exists.

One possibility to solve or at least mitigate this effect is to use a balanced readout, i.e. to use flow compensation. Then, the scenario for the readout direction gets also similar to Fig. 1. However, the slice direction with its unbalanced spoilers leads to effects as described in Fig. 2.

Discussion

It should be noted that the correction scheme for TSE sequences with very low refocusing flip angles such as SPACE still works very well despite of the pathway splitting. It is presumed that one major reason for this behavior is that all these TRAPS based sequences prepare magnetization close to the SPSS. In this condition, most of the magnetization possesses still a high coherence, i.e. resides in states of low dephasing in the EPG representation. These states are preserved or corrected with the suggested approach.

References

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