Single-Shot Diffusion-Weighted Spiral Imaging

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Introduction:

Spiral trajectories offer a range of desirable properties: short echo times, high SNR efficiency, a uniform point-spread function and a well-conditioned reconstruction problem for high reduction factors in parallel imaging, such as with circular coil-arrays as employed for head MRI. In diffusion weighted MRI (DWI), single-shot spiral imaging could increase the achievable SNR while providing robustness against motion.

However, single-shot spiral imaging is rarely applied in practice, since the achievable image quality and effective resolution is often poor. This is mainly due to the sensitivity of spiral MRI to B_0 off-resonance effects which worsen with the readout duration. Typical sources of B_0 off-resonance are Eddy currents, concomitant fields, system related B_0 drifts, physiological motion as well as static B_0 off-resonance caused by the object susceptibility.

Recent developments in magnetic field monitoring have made it possible to concurrently retrieve information about the encoding fields, allowing for an accurate description of the encoding process. It was shown that congruence among variably diffusion weighted scans can be achieved for DW-EPI by including spatially higher-order fields to the reconstruction. Similarly, reconstruction methods that depend on the input of parametric maps are likely to benefit from a geometry congruent among different scans.

In this work a comprehensive approach to single-shot spiral imaging is presented. Higher-order reconstruction [1] is applied including parallel imaging and static-off-resonance correction. Accurate information of the spatio-temporal encoding fields of spiral data, as well as B_0- and SENSE-maps is obtained by means of magnetic field monitoring. In-vivo results are presented.

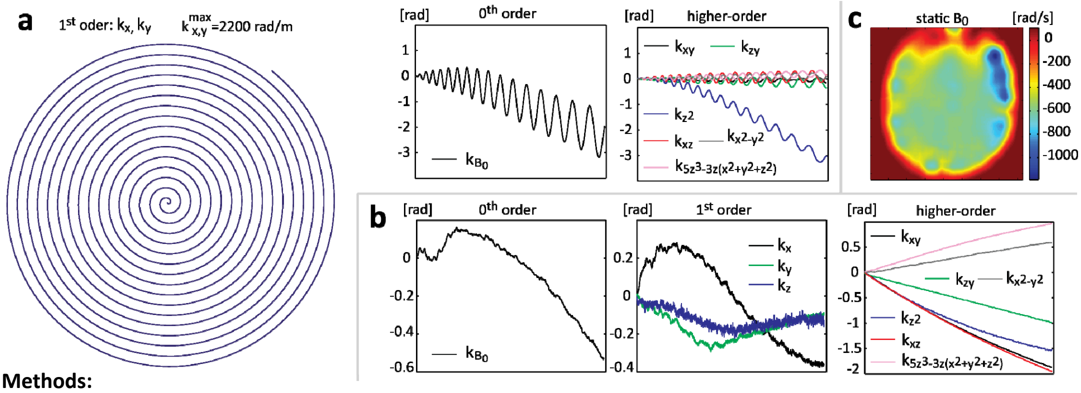

Figure 2: (a,b) Measured field information: Evolution during the single-shot spiral acquisition for the b_0 scan (a) and the differences when adding DW gradients to the sequence (b). All phase plots are scaled to show maximum phase within the imaging volume relating to each basis function. (c): static B_0 off-resonance map.

Methods:

Imaging data was acquired using an 8-element head-coil array on a 3T Achieva system (Philips Healthcare, The Netherlands). For all scans the 3rd order dynamic field evolution was recorded simultaneously to image acquisition using a concurrent monitoring setup based on 16 ^{19}F field probes [2]. In a first step, a 2D Cartesian gradient echo sequence (FOV = 23 cm, 160 phase encodes) using two different echo times (TE = 3.6/3.9 ms) was performed in a transverse plain. The same slice was subsequently acquired using a spiral single-shot spin-echo DW (b=0/1000 s/mm^2) sequence (FOV = 23cm, matrix = 166^2, res=1.4 mm^2, slice thickness = 4 mm, TE=51 ms, 5 averages) with 5-fold undersampling. For reference the sequence was repeated with the same parameters but fully-sampled (SENSE R=1) using 5 spiral interleaves and 1 average.

From the field probes data a 3rd -order spherical harmonic field model was fitted, describing the field evolution and thereby the spatial encoding for all scans. Subsequently, higher-order reconstruction [1] was performed on the basis of the measured field dynamics. In a first step the gradient echo images were reconstructed and B_1 sensitivity and static B_0 maps were calculated. Finally higher-order reconstruction was performed for single-shot spiral images with SENSE and static B_0 correction. The interleaved reference scan was reconstructed in the same way.

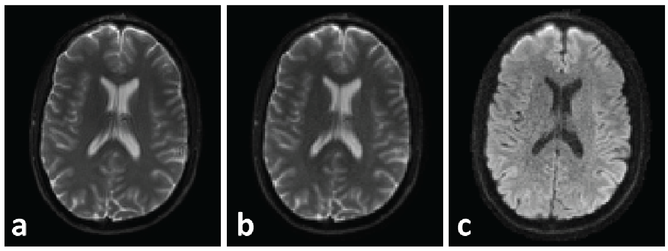

Figure 2: Interleaved spiral b_0 image (a), single-shot (b,c) 5-fold undersampled spiral (R=5): b_0 (b) and DW (b=1000 s/mm^2) image (c).

Results and Discussion:

The evaluation of the field evolution for the b_0 single-shot acquisition reveals relatively strong 0th order and higher-order effects, the latter may relate to concomitant fields from the readout gradients. The additional field effects from the diffusion weighting are shown in Fig.1b with the dominating effects relating to higher-order fields. Fig 1c shows the static B_0 map obtained from the two gradient echo images.

Fig 2a shows the in-vivo results for the interleaved spiral scan. Despite the long readout, off-resonance artifacts (which usually gravely affect spiral imaging) are not apparent (Fig2a-c). Even in case of 5-fold SENSE undersampling, the reconstructed single-shot b_0 (Fig.2b) and DW (Fig.2c) images show no fold-over related artifacts.

Conclusion:

A comprehensive approach to high-resolution spiral DW imaging was presented. The accurate description of the encoding fields obtained from concurrent field camera measurements served as the basis for the achieved image quality. The high parallel imaging reduction factor (R=5) is helping to achieve robustness against B_0 off-resonance artifacts, by keeping the readout reasonably short. The shortened TE and the associated SNR gain render single-shot spiral DWI an attractive alternative to the commonly used shingle-shot EPI sequences. The results suggest that even higher-reduction factors may be achievable to further increase image quality and resolution.

References: 1: Wilm et al., MRM (in press), **2**: Barmet et al. ISMRM2010,216.