High Resolution T2* weighted Reverse and Forward Spiral imaging at 7Tesla

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Introduction

Spiral imaging is known to be a very efficient acquisition scheme to sample data in k-space. Using a forward spiral approach (spiral-out) rather short effective echo times can be achieved (1). However, a number of applications, like functional brain MRI (2) or susceptibility weighted imaging (3), require long effective echo times to introduce an appropriate T2* contrast. To achieve this, reverse spiral imaging (spiral-in) has been proposed (4). Reverse spiral imaging facilitates T2* weighting by sampling the low spatial frequencies at long effective echo times without the need to increase TR. With the advent of ultra-high field systems, which help to boost the SNR, high-resolution anatomical imaging comes into the focus. Furthermore, susceptibility weighted imaging, benefitting from the high contrast present at these high field strengths, improves the visualization of a number of anatomical structures (3,5), allowing for excellent delineation of veins, mainly caused by deoxyhemoglobin, and white/gray matter structure.
In this work, the basic applicability of forward and reverse spiral imaging at 7T is investigated with respect to performance, necessary corrections and contrast properties. In-vivo results are shown and discussed.

Methods

Interleaved spiral imaging experiments were performed using a 7T scanner (Achieva, Philips Medical Systems, Cleveland). An integrated transmit / receive array head-coil (Nova Medical) was employed, allowing to switch between single channel (volume-coil mode) and 16-channel phased array acquisition mode. Imaging performance was tested for 2D and 3D (stack-of-spiral) acquisitions using different spatial resolutions while keeping the FOV and the spiral read-out window fixed (matrix size: 128² to 1024² with the corresponding number of interleaves: 12 to 500, FOV: 220×220mm², AQ window: 15ms, NSA: 1-4). A spoiled gradient echo acquisition was used with a TR of 60ms and TE of 21ms. To improve the B_0 homogeneity higher order shimming was applied, but fat suppression was not employed. K-space was traversed using forward and reverse spiral sampling employing a variable angular speed spiral. While the forward spiral is rather robust against flow effects, its first gradient moment is rather small for the low spatial frequencies (1), for interleaved reversed spiral sampling gradient moment nulling was implemented, applying a bi-polar gradient prior to reverse spiral sampling, to avoid artifacts caused by cardiac pulsation (3). Image reconstruction was performed on the system using conventional regridding.

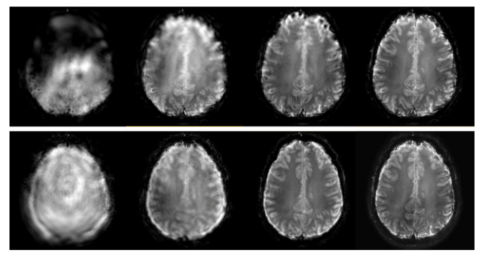

Fig.1.Interleaved T2* weighted spiral imaging with different spatial resolution (from left-right: matrix: 128², 256², 512², 1024²). Top row: forward spiral, bottom: reversed spiral. All spirals used the same FOV, TE (21ms), AQ window (15ms) and number of receive channels (16), no deblurring was applied.

Spiral imaging is known to be sensitive for off-resonance (6). However, it is assumed, that using a fixed data sampling window at a given off-resonance, artifacts are more severe in low-resolution than in high-resolution spiral. This is caused by different adverse phase accruals for the low spatial frequencies and the more relaxed gradient system requirements (slew-rate) in case of high resolution imaging. To cope with the off-resonance problem conjugate phase reconstruction (6) was performed as an off-line post-processing step based on a measured field map, acquired using a forward spiral imaging in volume-coil reception mode. Five healthy adults (23-27 years) were scanned in this study. Informed consent was obtained according to local IRB requirements.

Results and Discussion

All volunteer scans were successful and yielded good and reproducible image quality. The experiments confirmed the feasibility of high resolution forward and reverse spiral imaging at 7T. As expected, image quality degradation is reduced if spatial resolution is increased as shown in Fig.1. Forward and reversed spiral images show comparable contrast. Slight changes can probably be attributed to CSF flow or strong T2* relaxation at tissue boundaries resulting in considerable signal dephasing especially prominent in the forward spiral data. These effects are dominant for the high spatial frequencies which are either measured at the beginning (reverse spiral) or at the end (forward spiral) of the sampling period. Field map based deblurring is necessary for both spiral sampling types and shows remarkable improvements as demonstrated in the example shown in Fig. 2. However, the numerical effort is rather serious and scales at the moment with the number of channels and slices used. Thus, for a 1024² spiral, with 16 channels and a strong off-resonance variation roughly 8 minutes are needed on a standard PC. Efficient solutions to this problem are mandatory and conceivable.

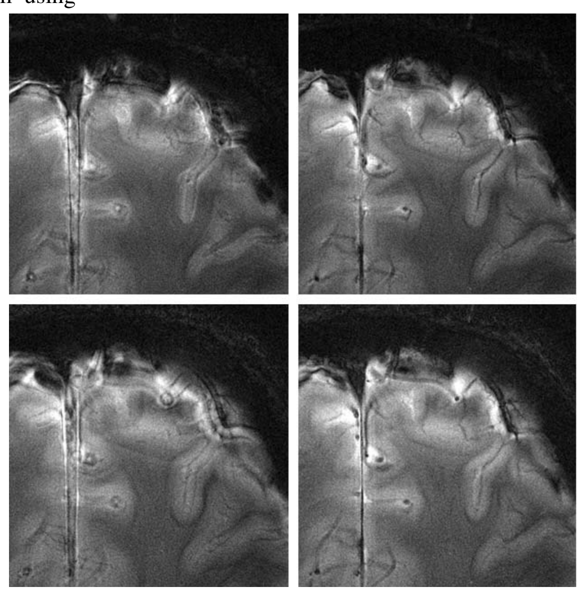

Fig.2. High resolution T2* weighted spiral imaging. (TE: 21 ms, AQ window: 15ms, acquisition matrix: 1024², 16 channel reception). Top row forward spiral, bottom row reverse spiral. Left before, right after deblurring, note off-resonance artifacts for reverse and forward spiral are comparable.

Conclusion

High resolution spiral imaging could find an interesting application in ultra-high field imaging. Reverse and long TE forward spiral imaging provides strong T_2^* contrast. The main advantage of the reverse spiral is the strong T2* weighting at short TR, which might be essential for dynamic studies where small repetition times and fast sampling is essential. Furthermore, it could enable shorter scan times for high resolution 3D imaging, thereby reducing the risk of motion artifacts.

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