PatLoc single shot imaging

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Introduction: It has recently been proposed to use non-linear gradient encoding fields in order to reduce peripheral nerve stimulation and to allow for spatially varying resolution in different areas of the field of view (FOV) [1]. The spatial encoding fields (SEMs) typically used in PatLoc (Parallel Imaging Technique using Localized Gradients) have the form $x^2 - y^2$ and $2xy$. Their non-bijective property is usually compensated for using parallel imaging techniques. So far all PatLoc studies were carried out using an in house manufactured prototype gradient coil [2], which was limited in terms of both slew rate and maximum gradient strength. An industrially built PatLoc gradient insert coil [3] makes it possible for us to attempt single shot imaging with state of the art performance. The aim of this study is to show the feasibility of spiral and echo planar imaging (EPI) using this new hardware.

Methods: Trajectories were calculated offline using Maltab (Mathworks, Natick, Massachusetts, USA). Spiral in and spiral out trajectories were calculated by optimizing to either the maximal slew rate or the Nyquist constraint, depending on which constraint is hit first at the particular position of the trajectory [4]. The Nyquist constraint is thereby given by the gradient momentum that induces a phase of 2π between the points of minimal and maximal magnetic field within the FOV of 224 mm. The base resolution was set to 64. The EPI trajectory was calculated for the same boundary conditions, employing ramp sampling. The endings of the readouts were connected using a time-optimal connection algorithm [5], which was also used for ramping up and down all trajectories. The resulting length of the spiral and EPI trajectories are 34.2 and 46.5 ms, respectively. A gradient spoiled gradient echo sequence was modified to read the gradient shapes from a text file. For comparison a standard EPI sequence was run on the linear gradients with a base resolution of 64 pixels and a FOV of 224 mm.

All experiments were carried out on a modified 3T Trio TIM scanner (Siemens, Erlangen, Germany), equipped with additional gradient power amplifiers to drive a dedicated head insert gradient system (Resonance Research Inc, Billerica, MA, USA). For signal reception an 8 channel receive coil was used.

Phase encoded calibration blips added to a 3D gradient echo sequence were used to calculate phase difference images and fitted to 4^{th} order spherical harmonics. B1 maps were calculated using the same acquisition, where individual coil maps were fitted in the complex domain using spherical harmonics up to 11^{th} order and extrapolated to fall of smoothly outside the object.

Image reconstruction of the PatLoc data was done by minimizing the cost-function $f(\vec{x}) = \left\| \mathbf{E}\vec{x} - \vec{S} \right\|_2^2$, where the forward operation is given by the matrix $\mathbf{E}$, which describes the spatially dependent phase evaluation along the trajectory multiplied with the sensitivity map of each receive coil element [6]. $\vec{S}$ contains MR-signals of all coils at all time points. In order to find the image $\vec{x}$, aforementioned cost-function was minimized using a conjugate gradient algorithm.

Results: Figure 1 displays the resulting image of the PatLoc-EPI trajectory, which shows the for typical PatLoc variations of the resolution. In comparison to the echo-planar image acquired with the linear gradients (Figure 2) a slight improvement of the resolution in the periphery of the object can be observed, even though the same number of phase encoding steps was applied. It must be noted though that PatLoc has an intrinsic parallel acceleration factor of 2 due to the non-bijective properties of the SEMs. The images acquired with the spiral trajectories show blurring typical for spirals and signal attenuation in the periphery of the object. The nature of the later artifact is yet unclear.

Discussion: The PatLoc-EP image demonstrates the feasibility of single shot imaging with non-linear SEMs. Using non-Cartesian trajectories like spirals for PatLoc-encoding, strong artifacts can be noted. The imaging behavior of non-Cartesian trajectories is generally less forgiving than that of EPI-trajectories. Therefore, imprecise calibration of the SEMs and the trajectory deviations, e.g. through eddy currents, may lead to strong image artifacts. This is probably the case for non-Cartesian trajectories with PatLoc encoding fields. This problem can be overcome by measuring the field evaluation along the trajectory with either field probes [7] or with a calibration measurement, which spatially encodes the entire phase evaluation [8]. In-vivo imaging will be attempted following the implementation of the IRB approved protocol for imaging with this new head gradient insert.

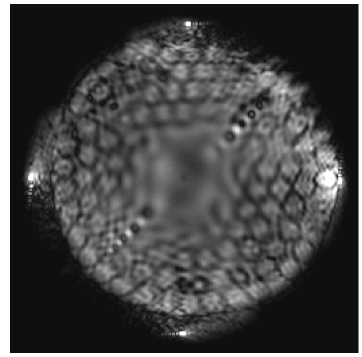

Figure 1: PatLoc EPI

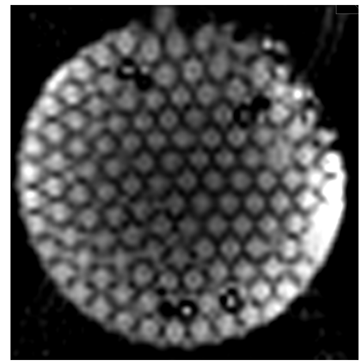

Figure 2: Reference image, acquired using linear gradients

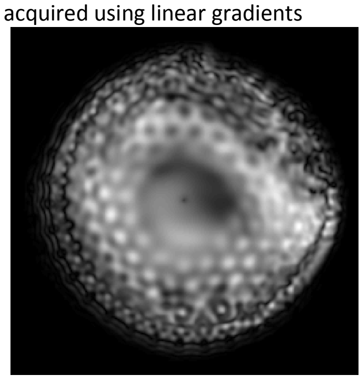

Figure 3: Spiral in-out

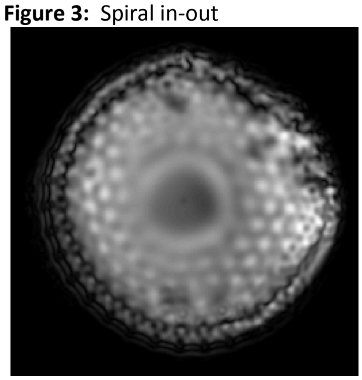

Figure 4: Spiral out-in

References: [1] Hennig, J., et al., MAGMA 21; 1-2:5:14 (2008); [2] Welz, A., et al., Proc. ISMRM 3072 (2009); [3] Zaitsev, M., et al., Proc. ISMRM 2591 (2012); [4] Glover, G., MRM 42:412-415 (1999); [5] Hargreaves, B. , et al. MRM 51:81-92 (2004); [6] Knoll, F., et al. MRM *in press* (2012); [7] Testud, F., et al., Proc. ISMRM 2598 (2012); [8] Stockmann, J., et al., MRM *in press* (2012);

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