Using Dedicated Fieldprobes for Trajectory Measurements in Parallel Excitation Experiments

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Introduction: Parallel spatially selective EXcitation (PEX) relies on an exact matching of RF pulses and a simultaneously traversed k-space trajectory. However, e.g. eddy currents or gradient amplifier bandwidth limitations may lead to deviations of the traversed trajectory resulting in reduced excitation accuracy due to the susceptibility of PEX pulses to trajectory errors [1]. Therefore, different methods for measuring actually traversed k-space trajectories and for calculating PEX pulses based on such calibration data have been presented and have proven to be advantageous [1,2]. However, most of the applied trajectory measurement techniques are based on phase evolutions in situ within the object and suffer therefore, especially at high field strengths and for long trajectories, from object-dependent limitations like fast T_2^* decays, off-resonances, intra-volume effects or motion artifacts. To overcome these limitations, this work exploits the field monitoring approach [3,4] using newly developed field probes on D_2O basis in order to achieve object-independent trajectory measurements. This allows a robust acquisition of calibration data for the calculation of PEX pulses and results in parallel excitation with high accuracy.

Material and Methods: PEX experiments were carried out in a T_1-doped water phantom and a rat (post mortem) using a 9.4 T Bruker BioSpec animal system with an 8-channel parallel transmit extension [5] and an 8-element TxRx coil array.

The k-space trajectories were measured with a newly developed D_2O fieldprobe (**Fig. 1**) consisting of a 5 µl droplet of pure D_2O within a micro TxRx coil encapsulated in an epoxy ellipsoid. The use of ^{2}D, whose gyromagnetic ratio is 6.5144 times lower than that of ^{1}H, eliminates the need for decoupling or shielding of the fieldprobe against the coil array used for proton imaging and offers therefore an convenient way for field measurements in parallel to proton experiments. Disadvantages of reduced signal intensity could be compensated for by an adequate probe size (see **Fig. 1**) resulting in sufficient SNR.

One single fieldprobe was attached to the measurement object with a certain offset to the gradient center in all three spatial directions and it was interfaced to an independent X-nuclei spectrometer channel operating at the ^{2}D frequency of 61.4 MHz. The probe position $\boldsymbol{p}$ was determined by a simple projection scan in three directions. For trajectory measurements prior to the PEX experiments the D_2O was excited by the microcoil and the phase evolution $\varphi_i(t)$ of the transverse magnetization was acquired while the gradient waveform to be measured was applied simultaneously. This measurement was repeated for each gradient channel i=x,y,z consecutively. For elimination of unwanted phase contributions (e.g. off-resonance, systematic sequence imperfections) the experiment was repeated without playing out the gradient waveforms resulting in a reference dataset $\varphi_{ref}(t)$. The traversed trajectory was calculated afterwards for the ^{1}H PEX experiments according to $k_i(t) = 6.5144\cdot[\varphi_i(t)-\varphi_{ref}(t)]/p_i$. For comparison the trajectories were also measured using the common in-situ multislice method according to Duyn [6] consisting in measuring the phase evolution within thin slices inside the objects.

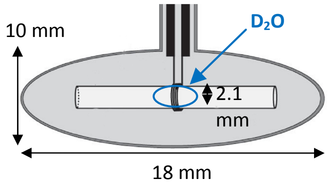

Fig. 1: Scetch of applied fieldprobe.

For the PEX experiments in this study, 2-fold accelerated spiral k-space trajectories were used for encoding a field of excitation of (64 mm)^2 / (40 mm)^2 with a resolution of (1.0 mm)^2 / (0.6 mm)^2 in the phantom / rat; pulses for the excitation of a checkerboard-like target pattern in the phantom and of a ROI covering the brain of the rat were calculated according to [2] based on the trajectory data measured with the fieldprobe.

Results: The signal of the D_2O field probe exhibits a very slow decay with a time constant T_2^* of approximately 200 ms at 9.4 T which is one order of magnitude longer compared to most in-situ measurements. Furthermore, given the gamma-ratio of 6.5144 between ^{1}H and ^{2}D, the fieldprobes used allow monitoring trajectories for ^{1}H image- / excitation-resolution of down to 160 µm. Beyond this value the gradient fields measured would cause intravolume dephasing leading to signal cancelation. **Fig. 2** shows the reconstructed spiral trajectories measured for the phantom and rat experiments firstly in situ inside the objects and secondly with the fieldprobe attached to the objects. In the phantom experiments (**Fig. 2**, top row) the fieldprobe measurements are in good agreement with the in-situ data, demonstrating the validity of the fieldprobe approach. However, in more complex objects like the rat (**Fig. 2** bottom row) the in-situ measurement frequently fails due to low signal intensities especially at the end of the trajectories, causing incorrect phase determination. This shows, that object-dependent factors like intra-volume dephasing, susceptibility gradients and T_2^* signal decay have a significant impact on the results of the in-situ measurements. On the opposite, the fieldprobe data exhibits practically no object dependency and much slower signal decays; furthermore slice selection gradients become unnecessary which eliminates the influence of undesired residual gradient effects and eddy currents on the measured phase evolution. These features result in a very reliable and robust trajectory determination by means of the fieldprobe measurements.

The results of the PEX experiments using the fieldprobe-measured k-space data are presented in **Fig. 3**. **Fig. 3a,c** shows the pilot scans of the phantom and the rat in which target patterns for excitation were selected. These target patterns were selectively excited by PEX with high accuracy (**Fig. 3b,d**), demonstrating the good adaptation of the RF pulses to the measured traversed k-space trajectory.

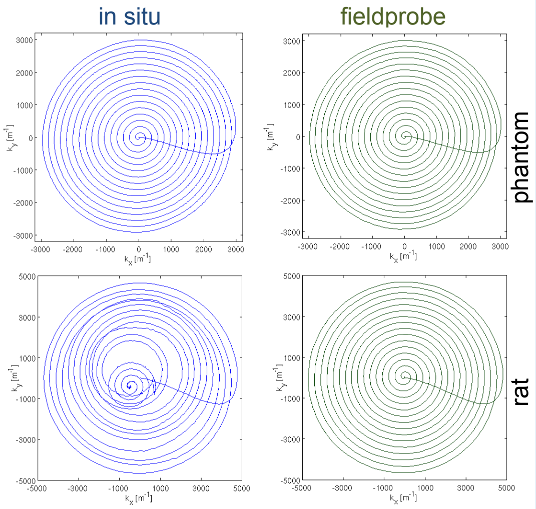

Fig. 2: Measured k-space trajectories.

Conclusion: This study demonstrates that the previously presented [1] potential of a trajectory measurement for high accuracy in parallel excitation can effectively be exploited by an object independent, robust calibration procedure using a dedicated fieldprobe. The use of different nuclei for the fieldprobe (e.g. ^{2}D) and for imaging (^{1}H) allows a comfortable setup and handling of the fieldprobe since coupling between the fieldprobe and imaging coils is avoided. The benefits over the common in-situ methods are significant especially in case of long trajectories or complex and structured objects. Minimal effort of attaching one single fieldprobe onto an object and connecting it to an existing spectrometer channel allows a very robust, convenient and object-independent measurement of an actually traversed k-space trajectory within seconds prior to the excitation experiment. The calculation of PEX pulses based on such measured data results in very precise excitation within an object. Applications like inner volume imaging in realistic and complex objects may greatly benefit from this technique. For detection of non-linear components of the gradient fields, which can be integrated into the pulse calculation process similarly [1], the approach of this study can be extended by the use of multiple fieldprobes at different positions according to the field monitoring approach presented in [4].

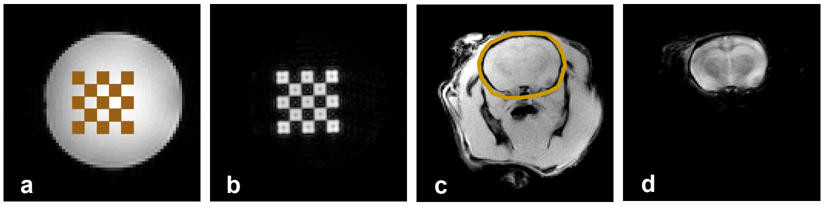

Fig. 3: Pilot scans of water phantom (a) and rat head (c) and 2D parallel excitation of a checkerboard pattern (b) and brain-ROI (d) acquired with a RARE sequence.

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