Inner-Volume-Imaging Using Three-Dimensional Parallel Excitation

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Introduction: Recently, first examples of inner-volume-imaging and motion artifact suppression based on Parallel EXcitation (PEX) have been presented [1]. However, in most PEX based applications, 3D selectivity has been achieved by 2D spatially selective excitation combined with perpendicular 1D slice selective refocusing. Therefore, the necessity of multi pulse sequences and the limitation to slice shaped preparation of the transverse magnetization in one direction prevented the application of PEX with its full potential. To overcome these limitations, this work presents the first experimental realization of 3D parallel spatially selective excitation of arbitrarily shaped regions of interest with very short pulse durations in the order of 5 ms. Such 3D selective pulses allow inner-volume-excitation and -imaging even with single pulse sequences and open up new possibilities for 3D PEX applications.

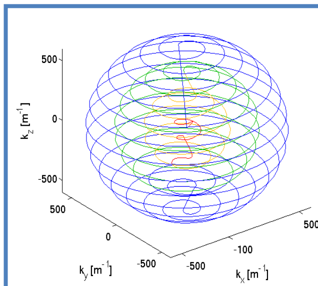

Fig. 1: Applied 3D shells trajectory: optimized and undersampled by a factor of 4 resulting in a duration of 5 ms.

Materials and Methods: The first step in this work was the selection of a suitable 3D k-space trajectory by means of a detailed simulation study [2]. A conventional stack of spirals trajectory was compared with a shells trajectory (**Fig. 1**) consisting of concentric spheres which are traversed on spiral like paths [3]. The simulation of point spread functions for both trajectories clearly showed the impact of the trajectory geometry and different undersampling schemes on the distribution of aliased signal and on the feasibility of reducing such aliasing artifacts by exploiting the specific spatial encoding capabilities of a given transmit array. In this study a TxRx coil array consisting of 8 elements in classical loop design arranged cylindrically around the z-axis of the MR system was used. Regarding this geometry, the shells trajectory with a combined undersampling scheme which reduces the number of spiral revolutions on each shell as well as the total number of shells yielded very good results. For further reduction of trajectory and pulse durations the traversal of the trajectory was temporally optimized by an algorithm of Lustig et al. [4] which allows playing out the trajectory always at the limit of the gradient system regarding gradient amplitude and slew rate. The combination of undersampling by a total factor of 4 and the temporal optimization resulted in a trajectory duration of 5 ms for encoding a field of excitation of $(6.4\ \text{cm})^3$ with a resolution of $(4\ \text{mm})^3$.

The experiments were carried out on a 9.4 T BioSpec small animal MR-scanner (Bruker BioSpin MRI, Germany) using the described 8-element coil array. In order to optimally match the actually traversed trajectory with the RF pulses, a trajectory measurement was performed prior to the PEX-scans. Trajectory data was acquired using a dedicated fieldprobe attached to the objects and the results were integrated into the PEX-pulse calculation according to [5]. PEX was applied to excite a 3D ellipsoid inside a bottle filled with T_1-doped water (**Fig. 2a**) and to excite an interactively defined 3D region of interest in a lemon (**Fig. 2c**). For excitation and acquisition a 3D gradient echo sequence in which the excitation pulse was substituted by the PEX module was applied.

Results and Discussion: Fig. 2b, d show the results of the PEX-experiments in three sections (xy-, xz- and yz-planes) of the acquired 3D datasets. The images demonstrate high excitation accuracy and good outer volume suppression. Off-resonance effects appear only marginally during excitation due to very short pulse durations of only 5 ms. As already found in the simulation study, the combination of the undersampled shells trajectory together with the used coil has proven to be very suitable to achieve acceleration factors of 4 without severe aliasing and backfolding artifacts during excitation. Since only negligible transverse magnetization was generated outside the specified target regions, the FOV for data acquisition could be reduced to the size of the excited ROIs without the risk of backfolding artifacts into the images. In this case, not the entire object has to be spatially encoded. Therefore measurement time can be shortened by reducing the number of phase encoding steps in two dimensions or spatial resolution can be enhanced if the number of encoding steps remains constant in the reduced FOV. **Fig. 2e** shows an example for this so-called reduced FOV / zoomed imaging in the lemon exhibiting now clearly visible structures of the lemon segment. A gain in resolution by a factor of 5 in all three spatial directions was achieved within only 4-fold prolonged measurement time (instead of a 25-fold extended duration as necessary for Full-FOV encoding).

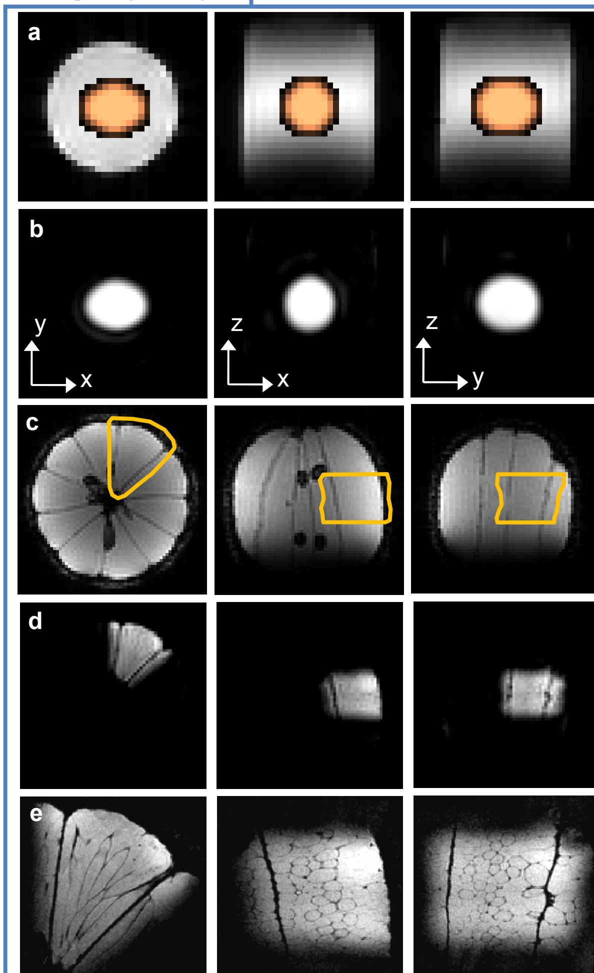

Fig 2: 3D pilot scans (xy-, xz-, yz-sections) of phantom (a) and lemon (c) with selected regions of interest. Results of 3D-PEX of an ellipsoid (b) and a lemon segment (d) acquired by a 3D gradient echo sequence within 7 min. Zoomed imaging (e) with 5^3-fold enhanced resolution within only 4-fold (instead of 25-fold) prolonged measurement time.

Conclusion: This work presents the first experimental realization of 3D parallel excitation of arbitrarily shaped regions of interest. Reasonable pulse durations down to 5 ms were achieved by PEX with an undersampled trajectory which exploits the encoding capabilities of the coil array very well and by a temporal optimization of the trajectory traversal. Due to this very short durations 3D RF-pulses are now on the verge of being used in common imaging sequences and were applied in first experiments for precise excitation and inner-volume-imaging in a phantom and a fruit. Reduced FOV and zoomed imaging was performed within reduced measurement time and / or with enhanced image resolution. Further investigations will focus on small animal in-vivo applications like 3D selective excitation of anatomical structures, multi-slice or even arbitrarily shaped multi-volume PEX and the extension of the presented technique for the purpose of 3D targeted spectroscopy.

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