Selective Excitation of Arbitrary Three-Dimensional Targets in Vivo using Parallel Transmit

Martin Haas[1], Jeff Snyder[1], Stefanie Buchenau[1], Denis Kokorin[1,2], Johannes T. Schneider[1,3], Peter Ullmann[3], Jürgen Hennig[1], and Maxim Zaitsev[1]
[1]*Department of Radiology, Medical Physics, University Medical Center Freiburg, Freiburg, Germany,* [2]*International Tomography Center, Novosibirsk, Russian Federation,* [3]*Bruker BioSpin MRI GmbH, Ettlingen, Germany*

Introduction

Two-dimensionally spatial selective excitation (SSE) of arbitrary regions of interest (ROI) allows for faster imaging and an increase of resolution in unchanged measurement time [1] as compared to excitation of complete slices. Also, neighboring regions that induce artifacts inside the ROI can be excluded via SSE thus improving image quality [2]. As SSE requires transmit k-space trajectories with corresponding dimensionality, RF pulses for SSE are generally longer than slice selective pulses and therefore also vulnerable to B_0 inhomogeneities. Parallel transmit techniques [3-5] exploit the spatial B_1 variation of multiple local RF transmit coils for additional spatial encoding and thus shorten the RF pulses. For SSE in three dimensions these challenges are further increased, requiring fast single-shot 3D trajectories. Using undersampling-optimized trajectories, three-dimensional SSE has been demonstrated recently in vivo on a small animal system [6] and in a phantom on a human system [7]. In this work, three-dimensional SSE of an arbitrarily shaped target is demonstrated in vivo in the head at 3T for the first time.

Methods

The experiments were performed on a 3 T Siemens MAGNETOM Trio, A Tim System, with 8-channel TxArray extension. For transmit, an 8-channel parallel transmit body coil was used, which is similar to [8] and integrated into the system instead of the product body coil. A standard Siemens 32-channel head coil was used for reception. A navigator scan was acquired in the head of a volunteer and the 3D excitation target was positioned in the brain, excluding the CSF (see Fig. 1). The field of excitation (FOX, see Fig. 1 solid line) was then adjusted to contain the head and the target was defined on a 32x32x32 grid. A multi-slice off-resonance map covering the FOX was acquired using a dual gradient echo sequence (see Fig. 2a). A corresponding multi-slice B_1 map was then acquired using a pre-saturated turbo flash sequence [9] (result for the first of eight channels is shown in Fig. 2b). Then, an 8-channel parallel transmit RF pulse was designed taking into account the B_1 and B_0 maps, sampled on the 32x32x32 target grid and using a slew-optimized shells trajectory (Fig. 2c) in transmit k-space, resulting in a pulse duration of 11.59 ms. The RF pulse design was performed using a conjugate gradient small tip angle design routine [10] implemented in multithreaded C and linked to a GUI in Matlab (The MathWorks Inc., Natick, MA). On a 32-kernel machine the pulse calculation took 30 s, using less than 1GB of memory. In a first experiment in which the field of view (FOV) matched the FOX, the excitation fidelity was assessed. A 3D FLASH sequence modified for arbitrary excitation RF and gradient shapes was applied with TE=9.1ms, TR=100ms, FOV=21cm x 21cm x 16.9cm, and an acquisition matrix of 64x64x26. In a second experiment, the FOV was reduced below the extent of the head in order to acquire the target region with higher resolution and in a shorter measurement time, using a FOV of 15cm x 15cm x 9.1cm on a 64x64x14 matrix.

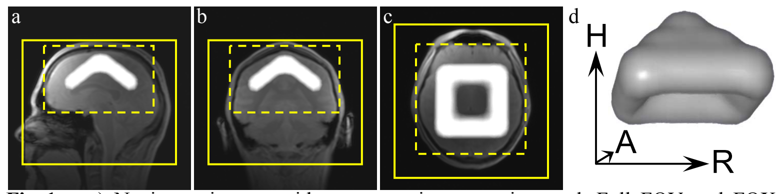

Fig 1: a-c) Navigator images with target sections superimposed. Full FOV and FOX (solid line) and reduced FOV (dashed line). d) Illustration of the 3D pyramid target shape

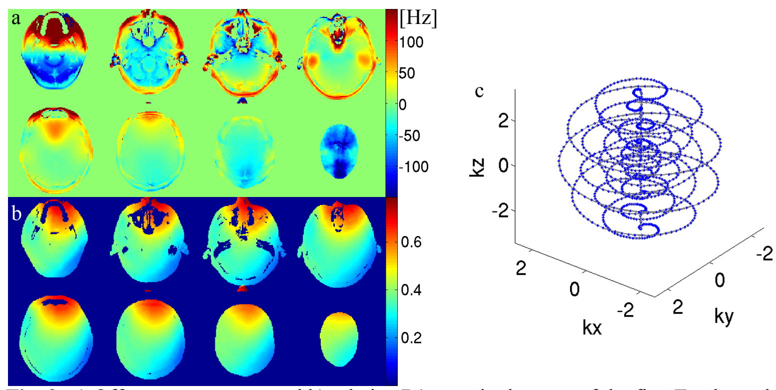

Fig. 2: a) Off-resonance maps and b) relative B1 magnitude maps of the first Tx channel, both covering the field of excitation. c) Three-dimensional transmit k-space "shells" trajectory with four shells and six revolutions per shell (units: 1/cm).

Results and Discussion

The experiment with full FOV (see Fig. 3) shows good excitation fidelity in all three dimensions, with a very low artifact level in slices outside the target shape. The quadratic pyramid target region, circumventing the CSF, is clearly visible. However, some subcutaneous fat signal is still present, preventing the FOV to be reduced much in the transverse plane. The good selectivity in the head-foot direction allows for a large reduction of the FOV in this direction. Figure 4 shows the result of the reduced FOV experiment, where the resolution is increased by a factor of 1.4 in both in-plane directions, and the acquisition time has been reduced from 167s to 90s, corresponding to a speed increase of 46%. The long TR and low signal level are due to very restrictive power limits necessary for obtaining IRB approval with the present RF coil, resulting in a maximum of 0.045 W/10s per TX channel. Also due to this limit, fat saturation was not effective.

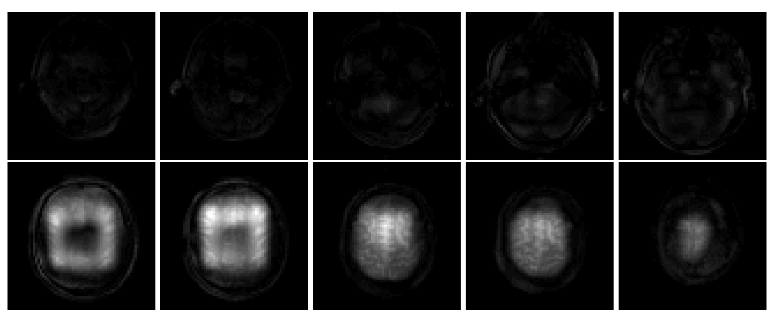

Fig. 3: Full FOV 3D FLASH acquisition of the head with 3D pyramid target excitation pulses (Ten out of 26 slices in ascending order), window/level=40/20.

Conclusion and Outlook

The feasibility of clean selective excitation of arbitrary 3D targets in vivo was demonstrated in the head at 3T, using parallel transmit and an optimized 3D trajectory in transmit k-space for acceleration, and a fast RF design algorithm including off-resonance correction. Consequent reduction of the field of view allowed for a faster acquisition of the region of interest with higher resolution. In the near future, a new parallel transmit RF coil will be available, allowing for an improved power budget.

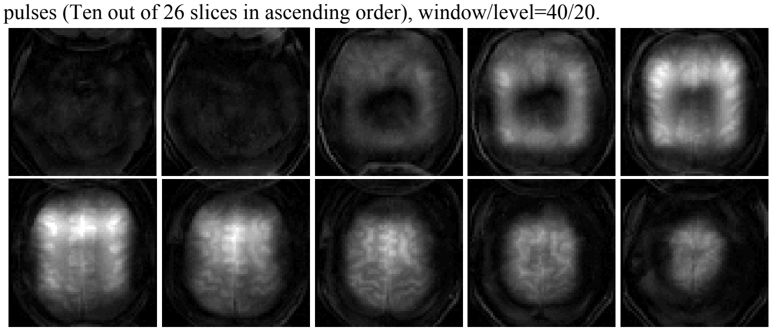

Fig. 4: Reduced FOV 3D FLASH acquisition of the head with 3D pyramid target excitation pulses (Ten out of 14 slices in ascending order), window/level=40/20.

References

[1] J. T. Schneider et al., Proc. ISMRM, p2601 (2009). [2] J. T. Schneider et al., Proc. ISMRM, p4606 (2009). [3] U. Katscher et al., Magn Reson Med **49**, 144 (2003). [4] Y. Zhu, Magn Reson Med **51**, 775 (2004). [5] P. Ullmann et al., MRM **54**, 994 (2005). [6] J. T. Schneider et al., Proc. ISMRM, p103 (2010). [7] M. Haas et al., Proc. ISMRM, p4433 (2010). [8] J. Nistler et al., Proc. ISMRM, p1027 (2007). [9] H.-P. Fautz et al., Proc ISMRM, p1247 (2008).[10] W. Grissom et al., MRM **56**, 620 (2006).

Acknowledgment This work is part of the INUMAC project supported by the German Federal Ministry of Education and Research, grant #13N9208.