Inner volume imaging of the kidney in vivo using parallel transmit

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Introduction

Inner volume imaging (IVI) with multidimensional spatially selective excitation (SSE) has received renewed attention with the introduction of parallel transmit (pTx) techniques [1-3], which are able to reduce the otherwise rather long SSE RF pulse durations. Especially small organs like the kidney can profit from IVI [4]: By reducing the field of view (FOV) to the excited organ, resolution and acquisition time can be improved compared to a full FOV encoding. For the kidney, clinical applications include MR angiography, tumor and metastasis screening, but recently also functional investigations have been demonstrated [5]. With the blood oxygen level affecting T2* (BOLD effect), it could be demonstrated how renal oxygenation changes in cortex and medulla under water loading [6]. This work presents in-vivo IVI with accelerated pTx SSE of the kidney of a healthy volunteer at a field strength of 3T, and first corresponding T2* maps.

Methods

For RF transmission (Tx), an eight-channel Tx/Rx body array (RAPID Biomedical GmbH, Rimpar, Germany) was used, consisting of strip line elements oriented in head-foot direction and connected to a 3T MAGNETOM Trio MR system, equipped with an 8-channel pTx extension (Siemens Healthcare, Erlangen, Germany). For signal reception (Rx), the posterior half of a 32-channel product body array (Siemens) was used. To ensure SAR-safe operation, a model of the Tx coil (≤1 mm in-plane resolution), inactive body coil and RF shield, together with a 3D whole body model of the actual volunteer (see Fig. 1a, ≤3 mm isotropic resolution), were simulated in SEMCAD X (Schmid & Partner Engineering AG, Zürich, Switzerland), resulting in field distributions for E, B, and 10 cm^3 averaged SAR (see Fig. 1b) for each Tx channel. The human model tissues were segmented based on a whole-body double-echo Dixon data set and included fat, muscle, gluteal muscle, bone, connective tissue, lung, air cavities and skin. A transversal B_1-map containing the kidney was acquired using a pre-saturated TurboFLASH sequence [7] with TR=1000 ms, TE=1.73 ms. Based on a localizer scan, a target ROI (Fig. 3a) containing the right kidney was defined and 2D selective pTx RF pulses were calculated using an image domain small tip angle algorithm [8], including the B1 maps (Fig. 2b) and a spiral k-space trajectory (Fig 2a) accelerated by two. The pulses, of duration 6.34 ms, were applied in the experiment using a segmented 3D EPI sequence, acquiring 5 k-space lines per repetition, with fat saturation. For IVI, the reduced FOV (see Fig. 3b, c) was used, with a coronal matrix of 128x55, 32 slices, a voxel size of 2.5x2.0x3.5 mm^3, TR=52 ms, TE=20 ms, and TA=18 s (one breathhold).

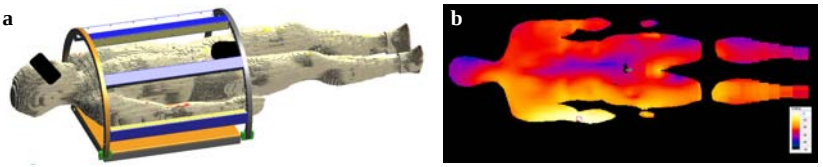

Fig.1: a) Models of the RF coil (casing shown) and of the actual volunteer used in FDTD simulations; b) Coronal slice of the 10 cm^3 averaged SAR distribution of one Tx element.

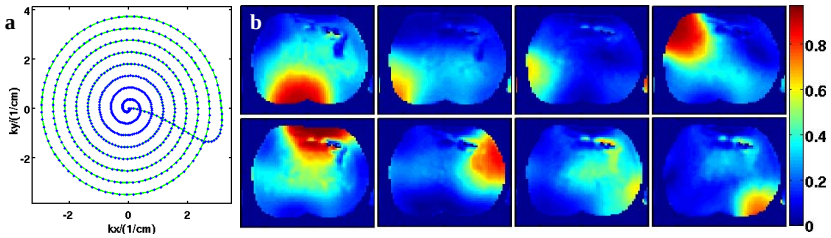

Fig. 2: a) Transmit k-space trajectory (acceleration two); b) Relative B1+ maps (Tx elements).

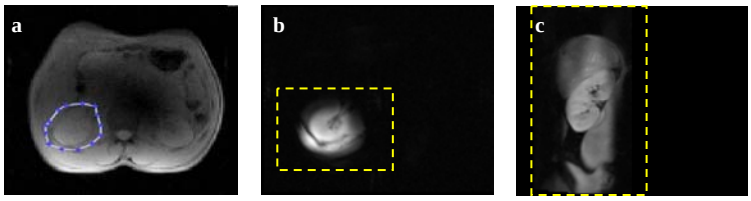

Fig. 3: a) Transversal localizer image and target region of interest (blue/white); b) Transverse slice and c) coronal slice showing excitation fidelity of 2D selective pTx RF pulse. The reduced field of view used in the following measurements is marked by yellow dashed lines.

Results

From the simulated SAR distributions, power limits for the Tx channels were calculated assuming a worst case field superposition at all times and locations. For a local SAR maximum of 20 W/kg (second level controlled operating mode, IRB approved) the power limits were 2.70 W/10 s and 1.35 W/6 min. Figs. 3b and 3c demonstrate the good excitation fidelity of the SSE pulses, using the minimum TE=5.1 ms for low T2* contrast. A central set of slices covering the kidney obtained from IVI is shown in Fig. 4. In Fig 5 one slice out of 32 is shown, acquired with different echo times, and a reconstructed T2* map, obtained by fitting an exponential signal model to the data after thresholding at 8% signal level.

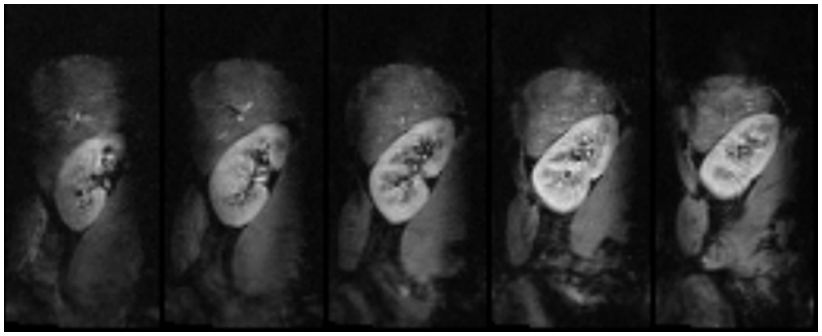

Fig. 4: Coronal inner volume imaging of the right kidney. Slices shown: 9, 11, 13, 15, 17 of 32.

Discussion

Compared to the corresponding full FOV sequence with equal voxel size, the IVI uses only 21% of phase encoding steps and 27% of the acquisition time thus making it possible to cover the kidney in one breathhold. The choice of a segmented 3D EPI helps to mitigate the impact of the increased SSE pulse duration vs. a slab selective pulse, as the excitation block duration loses significance compared to the signal readout duration. Compared to single shot EPI, which would be optimal in terms of duration, the segmented sequence is far less prone to image distortions. The T2* quantification needs to be improved in the future by acquiring more echoes.

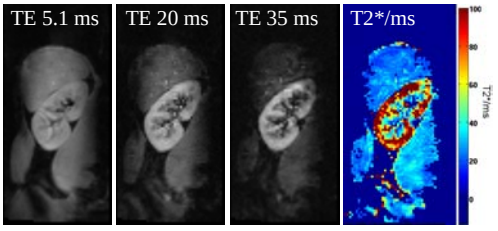

Fig. 5: Kidney IVI with different echo times, T2* map.

Conclusion

Inner volume imaging using pTx SSE pulses allows for increasing imaging resolution in small organs like the kidney, and reduces the acquisition time, allowing improved coverage of the kidney in one breathhold. As a next step, T2* will be compared quantitatively for different water loading of the healthy kidney.

References

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