3D BOLD-MRI at high PAT-factors: How to save time!

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Introduction

Regarding the worldwide increasing number of renal diseases, an early diagnosis of a renal impairment is very important not only for the purpose of an early treatment before severe organ damage occurs, but also to avoid kidney failure with the need of transplantation. To assess kidney function, the tissue oxygenation is a crucial parameter and shows a characteristic behaviour in pathologic cases [1]. In recent years, non-invasive blood oxygen level dependent (BOLD) MRI [2] has gained more importance in the entire field of MRI, not only for 2D and 3D head imaging, but also for its renal applications [3]. In contrast to cerebral imaging, renal imaging has to account for the respiratory cycle of the patient and hence, has to acquire images very quickly to allow for a breathhold examination avoiding severe motion artifacts. Furthermore, the acquisition scheme has to accomplish a sufficient resolution to be able to distinguish between different tissue compartments such as the renal medulla and the renal cortex. The aim of our work was to investigate the impact of the image resolution on the BOLD-evaluation. Therefore, we performed a clinical pilot study with four healthy volunteers and investigated whether the signal changes in the kidney induced by a pronounced water intake [4] could satisfactorily being followed utilizing three different optimized BOLD sequences (Fig. 1) with high parallel imaging acceleration factors for faster data acquisition.

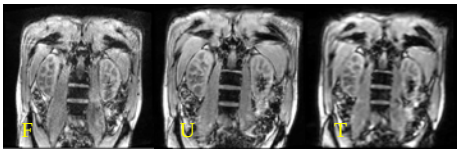

Fig.1. *Samples reconstructed from the first echo of the three different sequences (F, U, T) used in our study.*

Materials and Methods

We included four healthy volunteers (two male and two female) in our study with an average age of 43 years and an age range of 29 to 59 years. Every subject had to undergo a 10h diet without any food or drink intake prior to the examinations to maximize the BOLD-effect. The pre-waterload measurement was performed before a standardized break of 15 minutes in which each subject drank 1.0 litre of water. After this break, six post measurements followed the waterload, each with breaks of 5 minutes between the particular measurements. The whole study was performed on a Siemens 3 T Magnetom Skyra system (Siemens Healthcare, Erlangen, Germany) that allows, due to a novel multi-channel technique and an 18-channel body element coil, for a usage of high parallel imaging factors and hence a shorter acquisition time.

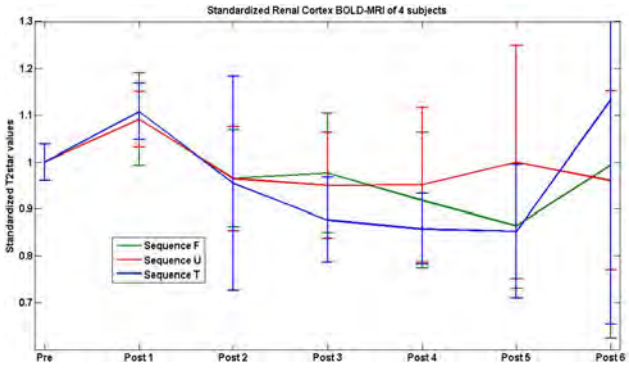

Fig.2. *Averaged T_2^* values acquired with the three different sequences (F, U, T) of our 4 subjects in the pre and post measurements. The values are standardized to the pre-waterload measurement.*

We investigated the application of three different 3D FLASH-sequences each with a different in-plane resolution to evaluate the impact of the different voxel sizes on the T_2^* calculations. Hereby, each sequence acquired 18 slices with eight echoes (3.3 ms – 21.1 ms) of a similar FoV in one breathhold and had a TR/FA/slice$_{Th}$=26 ms/20°/5 mm. The first sequence was a reference scheme (Sequence 'U') with an acceleration factor of 3, an undersampled matrix (factor 0.75) of 224 x 224, a subsequent in-plane resolution of 2.1 x 2.1 mm^2 and an acquisition time of 21s per slab. Sequence 'F' used a 224 x 224 fully sampled matrix and a GRAPPA factor of 6, leading to the highest in-plane resolution of 1.6 x 1.6 mm^2 and an acquisition time of 24s. The last sequence 'T' employed an undersampled matrix of 128 x 128 (factor 0.5) with an acceleration factor of 6, the lowest resolution of 2.8 x 2.8 mm^2 and subsequently the shortest acquisition (breathhold) time of 15s.

Postprocessing was performed offline, creating T_2^* maps of the pre and post measurements by fitting a monoexponential function pixelwise to the acquired image data (Fig. 3). Additionally R^2 maps were created to verify that only values with a high fit goodness are taken into account. To exploit the 3D acquisition scheme, we obtained several regions of interest from different slices to receive an averaged T_2^* value for the renal cortex for each of the seven pre- or respectively post-waterload measurements.

Results

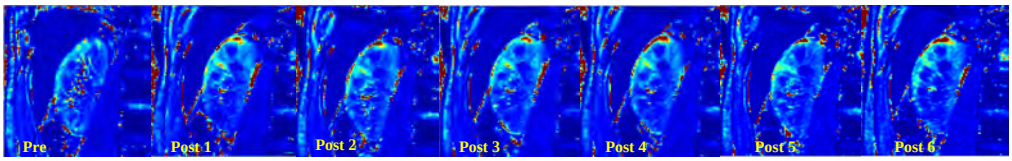

Fig.3. *Exemplary T_2^* maps of one subject depicting the pre-waterload and the six post-waterload measurements acquired with sequence 'U'. Especially the signal increase in the upper cortex from the pre to the first post measurement can clearly be followed.*

Figure 2 shows the time courses of the standardized T_2^* values averaged over six regions of interest (ROI) drawn in two slices for each time point and every subject. Despite the differences in resolution and acquisition time, the T_2^*-signal changes can clearly be outlined in all subjects, especially the water-triggered increase from the pre to the first post-waterload measurement and the decrease from the first post to the second post-waterload measurement. Data points after the third measurement show increased variances and errors. Quantitation of the initial T_2^* values prior to the waterload of the 4 subjects yielded nearly the same value (41.5±2.1ms for 'F', 43.0±2.1ms for 'U', and 40.6±2.9ms for 'T') and a high fit goodness with R^2 values from 0.89 to 0.96, as do the Post 1 (F/U/T=48.9ms/49.0ms/49.6ms) and Post 2 measurements (F/U/T=43.3ms/43.2ms/42.8ms) in accordance with values reported in [5]. Figure 3 depicts the calculated T_2^* maps for time points before and after the waterload. The increase of the T_2^* from the first image to the second (i.e. Post1) can easily be spotted on the left side of the kidney, as well as the decrease from the first post measurement to the second post measurement.

Discussion

Signal changes in the renal cortex triggered by the water intake could be sufficiently followed acquiring 8 echoes with all sequences. Hereby, results showed no dependence on the image resolution concerning the T_2^* values or the calculated time courses. This means that the sequence with the shortest acquisition time has no disadvantages compared to the sequence with the highest resolution and can be used to significantly shorten the acquisition time which leads to an easier application in patients with a reduced breathhold capability and a decreased probability of motion artifacts. The measurements after the second post measurement are marked by intensive inter subject variances which result in increased errors and an intensified deviation of the different data points with increasing measurement time. Looking at the fit goodness at later time points also shows a degrading tendency. This can be explained by the fact that the volunteers were in the scanner for over 30 minutes after they drank 1 litre of water and became more and more restless. A study with more subjects can probably smooth the individual deviation. In conclusion, 3D BOLD-MRI at high PAT factors is feasible and produces, compared to conventional techniques, reliable results and can hence be employed to allow for an increased patient comfort and a shortened acquisition time.

References

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