Real-time EPI T1, T2 and T2* mapping at 3T

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Introduction

Besides their usual methodological use to characterize the NMR characteristics of specific chemical drugs, T1, T2 or T2* mapping is now progressively used in neuro-scientific studies, for instance to better understand the structural modifications occurring during brain development. Despite major improvements using DESPOT1 and DESPOT2 pulse sequences [1], mapping the whole brain relaxometry still requires scan durations not always compatible with clinical use. In this abstract, we present a novel solution dedicated to perform ρ, T1, T2, and T2* mapping of the human brain in real-time with a low scan duration and a 1.5mm isotropic resolution, as previously proposed for diffusion tensor imaging [1].

Material and methods

DESPOT1 and DESPOT2 rely on SPGR and SSFP pulse sequence schemes to reduce the scan time, enabling the reconstruction of T2 and T1 maps in approximately 12 minutes [2]. Any T2 mapping depends on a preliminary estimated T1 mapping, leading to a 12 minutes acquisition even if only the T2 mapping is wanted. Moreover, T1 and T2 mappings are processed from two SPGR or SSFP acquisitions using only two different flip angles in order to preserve a reasonable scan time, which can reduce the accuracy of the estimates. Last, due to the 3D nature of these pulse sequences, any motion can cause severe artifacts, and no incremental processing of the T1 and T2 maps can be done during the scan.

Alternatively, we propose to use a variable inversion time (TI) inversion recovery spin echo EPI (IR-SE-EPI) pulse sequence to map T1 relaxation times, and a variable echo time (TE) spin echo EPI (SE-EPI) sequence to map T2 relaxation times, and a variable echo time (TE) gradient echo EPI (GE-EPI) sequence to map T2* relaxation times. Three EPI acquisitions were performed to recover the T1/T2/T2* maps of a human brain, on a Siemens Tim Trio 3T MRI system, equipped with a whole body gradient (40mT/m, 150T/m/s) and a 32-channel head coil.. Parameters common to the three EPI pulse sequences were: FOV=192mm, TH=1.5mm, matrix 128x128, RBW=1502Hz/pixel, 80 slices. Specific parameters were as follows: ***T1 mapping (IR-SE-EPI)*** partial Fourier 5/8, no parallel imaging, TE=30ms, TI=300-3000ms with 10 steps, TR=20.3s+TI, scan duration 4min; ***T2 mapping (SE-EPI)***, partial Fourier 6/8, GRAPPA factor 2, TE=30-250ms with 10 steps, TR=23.2s, scan duration 4min; ***T2* mapping (GE-EPI)*** partial Fourier 6/8, GRAPPA factor 2, TE=20-150ms with 10 steps, TR=15.2s, scan duration 3min.

The EPI pulse sequences were modified to send each acquired volume corresponding to a given inversion or echo time to a distant computer on which an incremental solver was implemented to estimate the ρ / T1 / T2 / T2* maps in real-time during the ongoing scan. A Kalman filter [3] was employed to solve incrementally the system based on the equations $S=|\rho.(1-2\exp(-TI/T1))|$, $S=\rho.\exp(-TE/T2)$, and $S=\rho.\exp(-TE/T2^*)$. Such equations are log-linear and can easily be adapted to the framework of a Kalman filter. Such a framework is dedicated to perform an auto-regressive estimation of the regressors, namely the ρ, T1, T2 or T2* maps, knowing a new acquisition of a volume at a given TI or TE (called the observation): the innovation corresponds to the discrepancy between the new observation and its prediction stemming from the underlying log-linear model; the regressors are then updated with the result of the product between the innovation and a gain processed from the knowledge of the previous covariance estimate and the model parameters of the current observation. The Kalman was implemented in C++ using the PTK real-time environment as previously introduced in [1] and was installed on a custom computer connected to the Siemens operator console.

Results and discussion

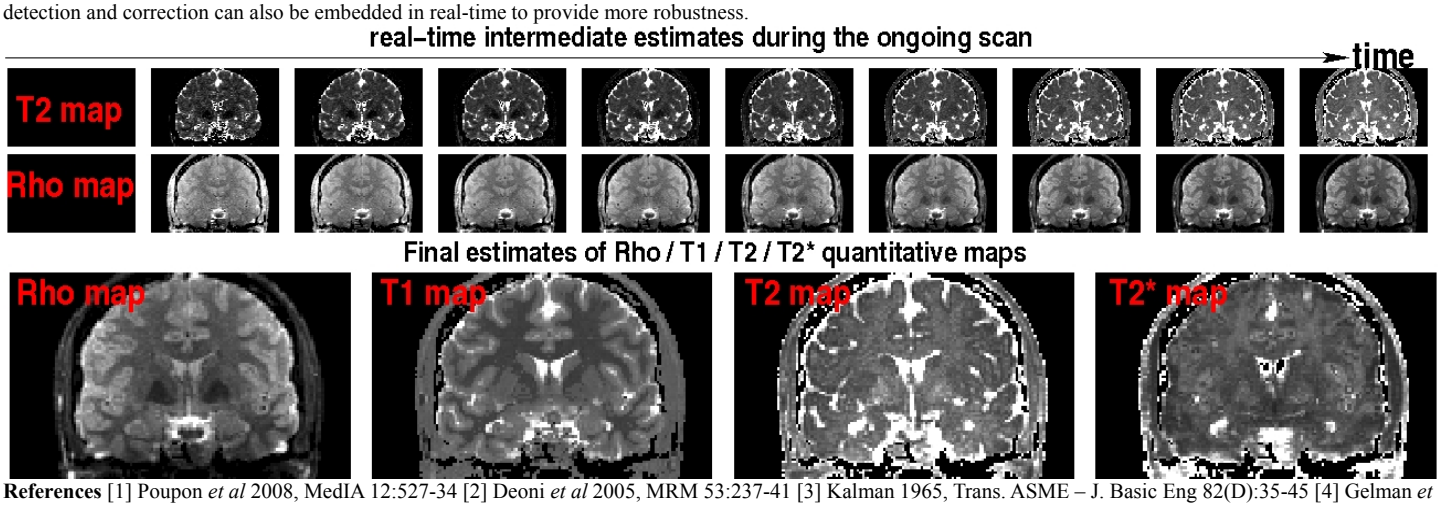
The pulse sequence schemes and incremental solver were preliminary validated on a phantom containing a solution of CuS04 with *a priori* T1 and T2 relaxation times. The obtained values were in good agreement with the known values, thus assessing the accuracy of the EPI-based acquisitions for performing real-time relaxometry.

The top part of the figure depicts an example of intermediate maps of ρ/T2 obtained during the ongoing scan after the acquisition of any new volume at various TE. The first intermediate results appear to be quite noisy, but become progressively reliable during the running scan, as expected.

The bottom part of the figure depicts the final ρ/T1/T2/T2* maps obtained independently from the 3 previous short acquisitions. The T1 & T2 relaxation times were also in good agreement with the values provided in the literature at 3T [4-5]: gray matter T1/T2~1300ms/100ms, white matter T1/T2~800ms/80ms. The T2* map shows a contrast that reveals the presence of iron with a high concentration in the pallidum, as expected. This improved contrast could be employed for their delineation. It is also interesting to observe that the proton density map provides a good contrast between gray and white matter, as well as on the pallidum. It seems interesting to observe that while the T2 mapping depicts a specific contrast at the level of the pallidum on the first estimated maps that progressively disappears after, the proton density mapping depicts a symmetrical phenomenon in time to finally provide a good contrast of the pallidum in the final ρ map.

Conclusion

We have proposed a novel technique to acquire and reconstruct ρ, T1, T2 , and T2* quantitative maps in real-time using variable TI or TE EPI based pulse sequences, embedded in an incremental Kalman framework to compute intermediate estimates during the ongoing scan. In opposition to DESPOT techniques, each map can be acquired and processed independently. Scan durations are limited to 4 minutes each for a total of 10 measurements per scan, providing a high accuracy of the estimates while preserving their suitability for clinical use. Unfortunately, the quantitative maps are entailed with the typical distortions of EPI due to susceptibility. However, if a field map was previously acquired, the incremental Kalman solver can easily manage an on-line correction of the susceptibility induced distortions. Last, motion detection and correction can also be embedded in real-time to provide more robustness.



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