Simultaneous Real-time Imaging and T2*-Mapping using a Radial Multi-Gradient Echo Sequence

S. Winkelmann[1], T. Schaeffter[2], H. Eggers[2], H. Dahnke[2], O. Doessel[1]

[1]Institute of Biomedical Engineering, University of Karlsruhe, Karlsruhe, Germany, [2]Philips Research Laboratories, Hamburg, Germany

Introduction

For a wide field of applications, such as quantitative susceptibility imaging, perfusion/angiogenesis imaging [1], and especially for MR-guided drug delivery [2] or labelled stem cell injection [3], real-time relaxation time mapping is of growing interest. A radial multi-gradient echo (radial EPI [4]) technique provides image data for T2* determination in hardly more than a common image acquisition time. In this work, radial EPI is used to enable the simultaneous generation of images and relaxation time maps in real-time including their online viewing.

Methods and Materials

After each excitation pulse, several (N) gradient echoes/profiles are acquired using an angulated EPI readout gradient. The profiles are sorted according to their echo-time into N undersampled k-space data sets (Fig.1). The reconstruction of these data sets yields N single echo images. The signal decay at each pixel over time is modelled by a numeric approach [5]. Based on this approach, T2* is computed as a weighted sum of the signal intensities at all echo times using the fast Simpson algorithm. Additional to the relaxation time map, a high-resolution image is computed as the sum of the first three single echo images. All imaging and reconstruction was performed *online* on a 3T whole body scanner (Philips, Intera) in real-time. Images and maps were displayed online simultaneously. For the evaluation and demonstration of the technique, the following experiments were performed:

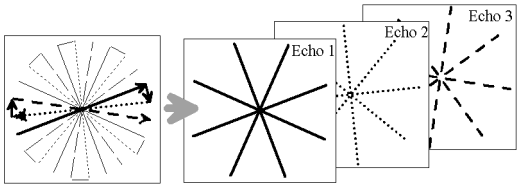

Fig. 1. Undersampled single echo k-space subsets,, allowing for the reconstruction of images at different echo-times.

1. *Fit evaluation*: The fit algorithm was evaluated using samples of diluted SPIO-based contrast agent (Resovist, Schering) in different concentrations (resulting in T2*=2-20ms) (FOV=200mm, matrix=256x256, slice=5mm, flip angle=20°, 132 profiles/echo, 5 echoes, TR=15ms). The fit results were compared with those of a non-linear regression using the Levenberg-Marquardt algorithm for high resolution cartesian images at 65 different echo times.
2. *Multi-stack injection monitoring*: Diluted Resovist with an R2* (=1/T2*) of 0.23ms^{-1} was injected into a piece of meat, and the distribution was dynamically monitored in two perpendicular slices. The R2* of the contrast agent derived by the map is evaluated. (FOV=270mm, matrix=160x160, slice=7mm, flip angle = 20°, 95 profiles/echo, 5 echoes, TR=9ms) → Tacq=2*0.8s
3. *Catheter visualization*: Small susceptibility markers were added to a catheter tube. The catheter was moved through a vessel phantom while monitored dynamically by means of the sequence presented in the second experiment. →Tacq=0.8s
4. *Cardiac function study*: Finally, the high resolution image and the R2*-map of a volunteer's heart were computed in a non-triggered dynamic experiment (FOV=340mm, matrix=128x128, slice=8mm, flip angle=20°, 66 profiles/echo, 5 echoes, TR=7.3ms) → Tacq=0.48s

Results

1. The accuracy of the fit is good for T2* in the order of TR (mean error 3,3% for ROIs within the compartments).
2. See Fig.2. The R2* of the contrast agent as derived from the R2* map was (0.20 ± 0.05) ms^{-1} within the region of contrast agent distribution, matching the expected value.
3. See Fig.3. The susceptibility artifacts, hardly visible in the high resolution image, appear clearly – showing positive contrast - in the R2*-map.
4. See Fig.4. The quality of the map may allow the visualization and quantification of labelled stem cells during injection.

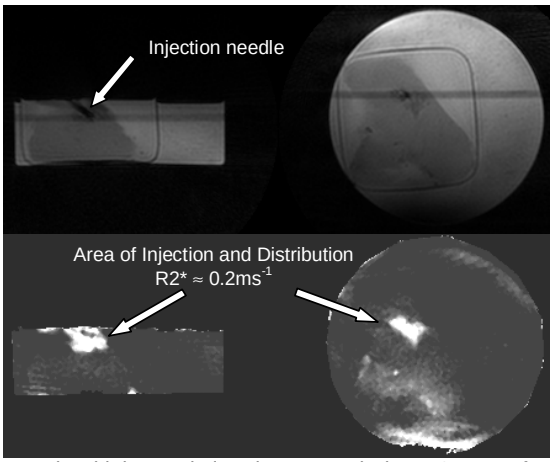

Fig. 2. The high resolution image and the R2*-map for two perpendicular slices. The injection was monitored for 16 s with an update rate of 1.6s.

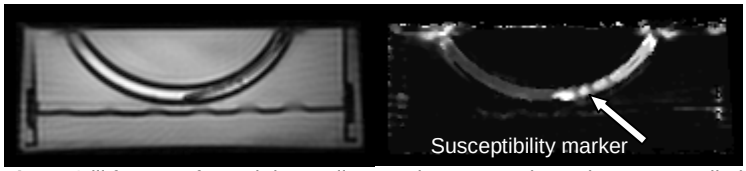

Fig. 3. Still frames of a real-time online movie stream. The catheter was pulled with constant velocity through a vessel phantom. The high resolution image and the R2* map were updated simultaneously all 0.8s.

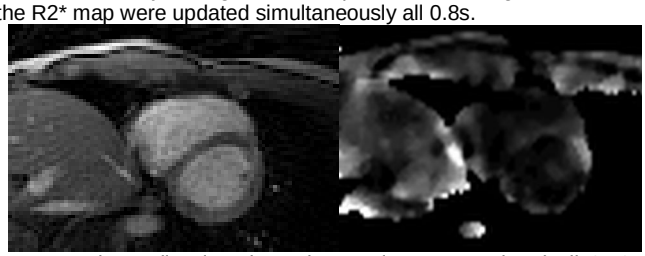

Fig. 4. Dynamic cardiac imaging. The results were updated all 0.48s. The myocardium is clearly detectable while stable results are achieved for the R2*-map.

Discussion/Conclusion:

The error of the Simpson algorithm for the T2* determination decreases for an echo-spacing much shorter than T2* and short echo trains, assuming an ideally decaying signal. However, as the ideal decay is corrupted by noise, the echo train (approx. repetition time TR) has to be chosen long enough to provide stable fit results even for long relaxation times. Reasonable results were achieved for echo-train lengths in the order of T2*. The combination of radial EPI for single echo data acquisition and a numeric fit algorithm enables T2* determination in real-time. The approach is especially useful for the quantitative monitoring of local SPIO-based drug delivery and labelled stem cell injection.

References:

[1] Bremer C, et al., Rad. 226(1): 214-220 (2003)
[2] Nijsen JF, et al., Rad. 231(2), 491-499 (2004)
[3] Dick AJ, et al., Circulation 108(23): 2899-2904 (2003)
[4] Silva AC, et al., J. Magn. Res. 135, 242-247 (1998)
[5] Hagberg GE, et al., MRM 48, 877-882 (2002)