An improved method for self-gated Cardiac T1 mapping in mice

Patrick Winter[1], Thomas Kampf[1], Xavier Helluy[1], Fabian Tobias Gutjahr[1], Cord Bastian Meyer[1], Eberhard Rommel[1], Wolfgang Rudolf Bauer[2], Peter Michael Jakob[1], and Volker Herold[1]

[1]*University of Würzburg, Würzburg, Bavaria, Germany,* [2]*Universitätsklinik Würzburg, Würzburg, Bavaria, Germany*

Target Audience

This report could be relevant to everyone who does cardiovascular MR (especially T_1 measurements) in small rodents and is interested in self-gating techniques.

Purpose

The longitudinal relaxation time T_1 is an important parameter for the assessment of morphological and functional information in the cardiovascular system. In recent studies MRI methods have been developed to measure T_1 in the murine myocardium, e.g. using an Inversion Recovery Snapshot FLASH (IRSF) sequence with a Look-Locker read-out[1,2]. Conventionally triggered measurements in the mouse model using ECG can be difficult since rapid switching of the imaging gradients often compromise the trigger signal[3]. It could be shown that a radial k-space trajectory provides an alternative for more robust T_1 measurements without the need of additional triggering hardware[4,5]. However, it became apparent that the entire removal of the multi-exponential relaxation behavior of tissue and blood is challenging. The global inversion of the blood signal, for instance, leads to a 180° phase shift of the cardiac waveform at the zero-crossing point (Figure 1a), which needs to be corrected separately from the removal of the relaxation background. In this work an improved method is proposed, which almost completely removes relaxation behavior and phase shift from the signal and can be used for the extraction of a radial self-gating signal for global and slice-selective T_1 measurements.

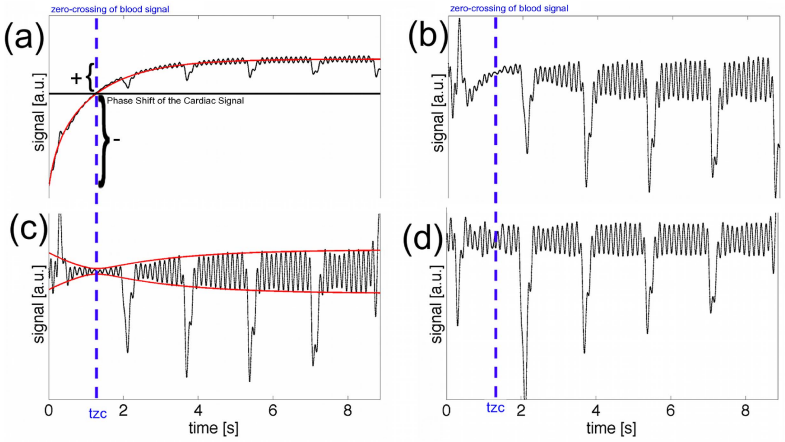

Figure 1: (a) Multi-exponential Least-Squares Fit (red line) of the self-gating signal. (b) Signal after subtraction of the fit function. (c) Signal after baseline correction and mono-exponential fits of the extremes of the cardiac amplitudes (red lines). (d) Signal after normalization and phase shift correction. The blue dashed lines mark the zero-crossing point of the blood signal.

Methods

All measurements were carried out on a 7 T small animal system with a 72 mm quadrature birdcage coil as transmitter and a 30 mm 4-channel array as receiver. Global and slice-selective cardiac T_1 measurements were conducted in a healthy mouse using the previously described radial retrospective IRSF sequence[2,4,5]. The experiment consists of alternating global and slice-selective measurements with 32 inversions, respectively. Each inversion contains 3200 golden-ratio distributed asymmetric radial read-outs, which are acquired without triggering. In case of the global inversion experiment the following workflow was implemented: The real value of the centric k-space signal of the receiver coil closest to the heart was low-pass filtered and fitted with a multi-exponential Least-Squares fit (Figure 1a, red line). The fitted function was subtracted from the signal to remove the background (F1b). Residual low-frequency modulations were afterwards removed with a baseline correction (F1c). To eliminate the remaining exponential amplitude variations caused by blood relaxation, the signal was normalized with the average of two mono-exponential Rice fits of the maxima and minima of the cardiac waveforms (F1c, red lines &d). The zero-crossing point of blood (t_{zc}, blue dashed lines) was assessed from the average minimum position of both Rice fits. All signal points on the left-hand side of the zero-crossing point were inverted to correct for the phase shift caused by the inversion of blood signal. For the slice-selective inversion the data processing steps (a-c) were identical, however, step (d) was skipped since the inversion of blood signal could be neglected due to the fast inflow of non-inverted blood into the left ventricle. Both extracted self-gating signals were afterwards used for the calculation of trigger points for a retrospective projection selection, as described previously[4,5]. Projections corresponding to the end-diastolic heart cycle phase were combined to reconstruct 200 T_1-weighted time frames along inversion time dimension for a global and a slice-selective T_1 fit[6].

Results

To assess the trigger quality an additional ECG signal was simultaneously monitored. The temporal deviations between the k-space trigger and the ECG reference were determined (Figure 2a&b). For the global inversion experiment (F1a) it can be noted that the temporal error is less than ±5 ms even at the beginning of the inversion, where relaxation has the strongest dynamic, and no phase shift relative to the reference is visible. Only in a small interval around the zero-crossing point of blood (t_{zc}≈1.3 s) higher deviations are visible. In case of slice-selective inversion the error is less than 5 ms at any point in time (F2b). The Figures 3a and b show the reconstructed global and slice-selective T_1 maps for the end-diastolic heart cycle phase (resolution: 312.5x312.5 µm^2) using self-gating as well as the ECG signal for projection selection. Both reconstructions match well, as can be seen in the error maps.

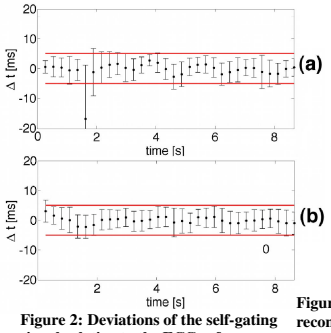

Figure 2: Deviations of the self-gating signal relative to the ECG reference. (a) Global. (b). Slice-selective.

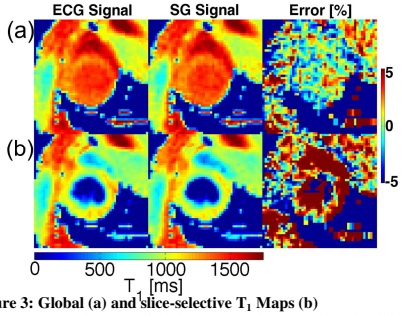

Figure 3: Global (a) and slice-selective T_1 Maps (b) reconstructed with the ECG signal and with the self-gatig (SG) signal for the end-diastolic heart cycle phase and corresponding error.

Discussion and Conclusion

In the present study the retrospective triggering during relaxation could be demonstrated to work for both the global and the slice-selective inversion. Both self-gating signals provide a stable wireless triggering signal. In case of global inversion self-gating fails in a small interval (≈0.3 s) around the zero-crossing point of blood due to the low SNR of the cardiac signal, which was therefore gated out. However, the reconstructed T_1 maps match well with those determined with the ECG signal. For a further improvement one might use interpolation to assess the missing trigger points. However the self-gating signal is already a promising alternative to conventional triggering due to its strong robustness against extraneous disturbances and due to its easy implementation.

References

[1] Streif et al., Magn Reson Med, [2005]; 53:584-592
[2] Kampf et al., Magn Reson Med, [2013];
[3] Polson et al., Clin Phys Physiol Meas [1982]; 3(3): 231-234
[4] Winter et al., Proc. Intl. Soc. Magn Reson Med [2012], 2031
[5] Winter et al., Proc. ESMRMB [2012], 121
[6] Deichmann et al., JMRI [1992]; 7:608-612

Acknowledgments:
This work was supported by grants from the Deutsche Forschungsgemeinschaft (SFB 688 B4, B5, Z2) and the Bundesministerium für Bildung und Forschung (BMBF01 EO1004)