Characterizing Temporal B_0 Field Changes in the Rat Heart

R. D. Dortch[1], M. D. Does[1]

[1]Vanderbilt University Institute of Imaging Science, Vanderbilt University, Nashville, TN, United States

Introduction: Quantitative NMR measurements in the rat heart are made difficult by the presence of myocardial wall motion, respiratory motion, blood flow, and substantial background magnetic field gradients caused by the susceptibility difference that occurs at the lung-myocardium interface [1]. The negative effects of motion and blood flow can be minimized through gating of the acquisition to the respiratory and cardiac cycles. However, complete removal of susceptibility induced gradients is often not possible as they tend to be highly non-linear, requiring higher order shim gradients than are often available. Even if these background gradients could be removed at one point in the cardiac cycle, myocardial motion may result in time-varying background gradients that cannot be corrected for with static shims. In order to ensure that quantitative NMR measurements in the rat myocardium reflect intrinsic tissue properties, both the static and dynamic characteristics of susceptibility induced background gradients in the rat myocardium need to be characterized.

Methods: All imaging was performed on adult Sprague-Dawley rats using a 4.7 T Varian magnet. Animals were anesthetized using an isofluorane/oxygen mixture throughout the experiment. Temperature was monitored and maintained at 37ºC with a warm-air feedback system. Respiratory and cardiac signals were monitored and used to gate all acquisitions. Following careful manual shimming, field maps (B_0) were measured (n=3) in three consecutive short-axis slices of the rat left ventricle at several points in the cardiac cycle. In order to assess the effect of time-varying field gradients on quantitative NMR measurements, transverse relaxation rates (R_2 and R_2^*) were measured (n=1). R_2 was measured in the central slice for which field map measurements were made during both systole and diastole using a CPMG sequence with two different echo spacings (Δte = 6.5,10 ms). R_2^* was measured in the same slice during both systole and diastole using a multiple-echo gradient echo (MEGE) pulse sequence (Δte = 2 ms). All images from different phases of the cardiac cycle were co-registered to a "global" left ventricle using a non-rigid, model-based registration technique similar to that proposed by Papademetris *et al* [2]. Field gradients were estimated in the x-, y-, and z-directions from the measured field maps. The estimated field maps and gradients were then interpolated temporally for subsequent analysis. The effect of the off-resonance field on the non-selective refocusing pulses used in the CPMG sequence was analyzed. Also, the effect of time-varying background gradients on echo magnitude was calculated for both CPMG and MEGE pulse sequences. The magnetization at the n^{th} echo in the CPMG sequence in the presence of both of these effects can be described by

$$M(t_n) = M(0)\exp\{-t_n R_2\} * f_{GT}(t_n) * \prod_{i=1}^{n} f_{RF}(i) \qquad (1)$$

where f_{GT} is the fractional signal loss due to time-varying background gradients and f_{RF} is the fractional signal loss due to imperfect RF refocusing [3]. The magnetization at the n^{th} echo in the MEGE sequence can be described similarly, replacing R_2 with R_2^* and removing the f_{RF} term in eq. (1).

Results and Discussion: The calculated field maps for the central short-axis slice of all three rats are shown in Figure 1. The highest off-resonance values in all three rats corresponded to areas near the lung-myocardium interface. Also, it can be seen that B_0 was not static throughout the cardiac cycle in all three rats. From calculations of R_2 with and without correction for fractional signal losses due to time-varying background gradients (f_{GT}), it was found that time–varying field gradients had little effect on all R_2 measurements (< 0.2%). The effect of off-resonance refocusing pulses (f_{RF}) was found to have a slightly larger effect in areas near the lung-myocardium interface (≈2-5%). The number of echoes used in this analysis was limited by the available SNR to 6. As this number is increased, the effect of off-resonance refocusing pulses on R_2 measurements should increase. As expected, the effect of time-varying background gradients on R_2* measurements was more significant. A decrease in myocardial R_2^* from 55.9±16.5 s^{-1} to 51.9±16.3 s^{-1} was found after correction for fractional signal losses (f_{GT}) in data acquired during diastole. A similar decrease in myocardial R_2^* from 51.0±10.9 s^{-1} to 48.1±11.3 s^{-1} was found after the same correction during systole.

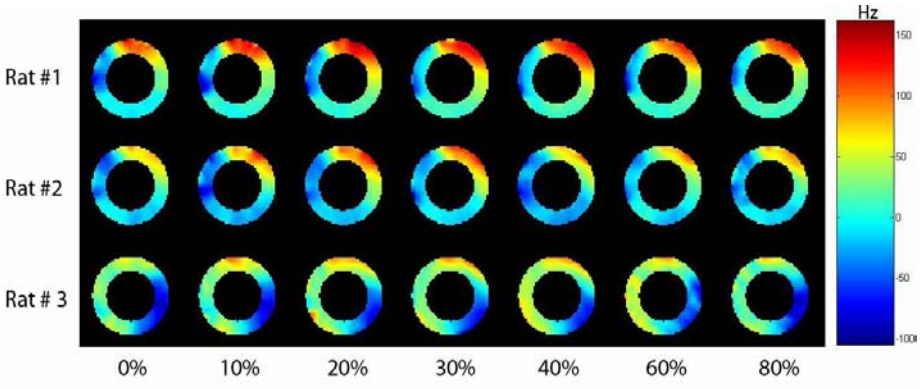

Figure 1. Registered B_0 maps of the central short-axis slice for each rat (top to bottom) left ventricle at different points in the cardiac cycle (left to right). Points in the cardiac cycle are listed as a percentage of the RR interval.

Conclusions: Magnetic field gradients caused by the susceptibility difference at the lung-myocardium interface were shown to exhibit temporal variation over the cardiac cycle. This may have significant effect on some quantitative NMR measurements and should be considered, and possibly corrected for, in such cases.

References: [1] Atalay MK *et al*. *MRM* 2001;**45**:341-345. [2] Papademetris X *et al*. *IEEE Trans Med Imag* 2002;**21(7)**:786-800. [3] Does MD and Gore JC. *NMR Biomed* 2000;**13**:1-7.

Acknowledgements: The authors would like to acknowledge financial support from the NIH, Grant #EB001744.