Efficient quantitative 23Na concentrations of fast and slow T2 components in the human heart using UTE-CSI and the blood pool as a reference.

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Introduction

Sodium concentrations in the human heart increase during ischemia due to failure of the Na-K pump, which results in increases in intra-cellular Sodium (^{23}Na). This has been demonstrated extensively in animal systems [1], and has been demonstrated to a lesser extent in humans [2]. Here we describe some technical developments that further advance this field. ^{23}Na exists as a 3/2-spin nucleus its quadrapolar moment results in it having bi-exponential relaxation under typical biological conditions. The relative concentration of these two relaxation components, and T_2's of each of these components may indicate the environment of the nucleus. The sum of these two components yields the total sodium concentration.

Theory

Use of the ultra-short TE Chemical Shift Imaging acquisition method allows us to acquire images with a TE as short as 70us, and to acquire the free-induction decay so as to capture both the short and long T_2 components efficiently[3]. After reconstruction we can fit the two relaxation components to evaluate the relative amounts and relaxation rates of the two signal components.

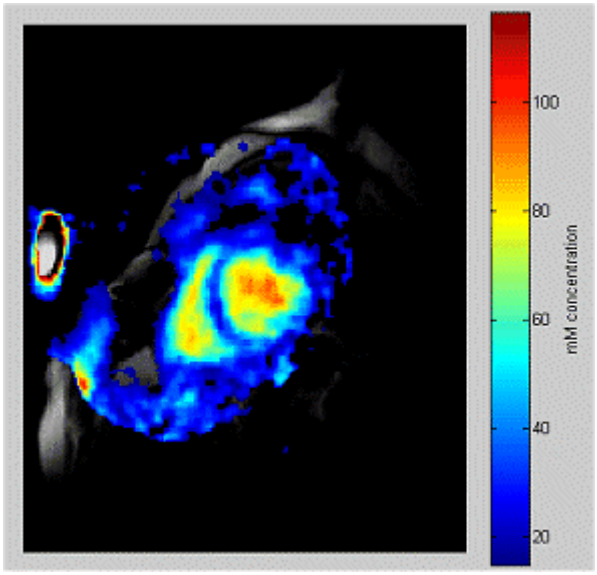
To provide quantitation we use the blood pool as a reference. The left ventricular blood pool is a good choice for a reference as it has a known Na concentration 135mM/l - 145mM/l, which can tested, has a similar T_2 to the myocardial tissue, contains a high level of Na, and finally is located close to the tissue of interest and hence will be similarly affected by the transmit RF fields.

Methods

All work was performed on a Siemens Sonata 1.5T system with multinuclear capabilities and a ^{23}Na coil (Rapid-Biomedical). UTE-CSI was used in a cardiac gated fashion using the Ernst angle and a repetition time of 20ms. Five supine male volunteers were imaged the sodium acquisition required around 25minutes (dependent on heart rate) total exam time was around 40minutes. Fiducial markers and proton images were used to determine the exact coordinates of the RF coil for each run enabling correction of the Receive field profile.

Results

An example image of the long T_2 component is shown in figure 1.



Relaxation and concentration parameters for the heart as a whole are shown in the table. The blood pool contains tiny amounts of short T_2 components. Each of the 16 segments of the conventional cardiac model were analysed. Regionally consistent long T_2 relaxation rates were found, but the T_2 of the short relaxation rate could not be quantified regionally owing to the noise level. Concentrations of the long T_2 component were regionally comparable with lower values in the septal regions, and coefficients of variation of ~15%, short T_2 concentrations (using a T_2 value of 1.21ms) exhibited high coefficients of variation ~60%. This high variability in these regional measurements is due to the intrinsically low SNR of the ^{23}Na acquisition.

Group	Total left ventricular myocardial wall Na concentration			Relaxation time	
	Long T_2 (mM/l)	Short T_2 (mM/l)	Total Na (mM/l)	Short T_2 T_2* (ms)	Long T_2 T_2* (ms)
Volunteers	43.6±1.9	10.5±2.4	54.1±2.9	1.21±0.45	18.4±1.6

Discussion

Previous quantitative sodium work on the human heart has been sucessful in quantifying the total sodium concentration [2], but required the use of "long" TR (approximately 5 T1's) to eliminate the effects of T1 variabilitiy. The consequent disadvantage of that technique is reduced SNR efficiency, which we have attempted to overcome in this work. The price paid for the increased efficiency obtained in this work is a small increase in complexity, and a requirement for some additional assumptions, which though validated in the literature but may not stand-up to more rigorous testing.

Regarding the short T2 component of the sodium signal, it is clear that this is very difficult to capture with high SNR in normal healthy tissue, but may become feasible in diseased tissued that demosntrate extreme fibrosis.

Conclusion

A method has been described and validated that allows quantitative measurements of the Na concentration in the myocardium using a time efficient acquisition. Short T_2 components can be separately evaluated using this approach, but have low SNR. The basis of the method is the knowledge that the blood in the blood pool has the same T_1 and observes the same transmit field as the ^{23}Na in the myocardium. This simplification removes complex corrections and their associated error sources from the calculation.

References: 1)Constantinides CD, et al. MRM 2001;**46**(6):1144.
2)Ouwerkerk, R, et al. JMRI 2005;21(5):546
3)Robson MD, et al. MRM 2005;**53**(2):267