In vivo sodium T1 and T2 measurements in human calf at 3T

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Introduction: Sodium MRI has been used as a biomarker of a wide range of diseases, such as ischemia, cancer, edema, osteoarthritis, and hypertension [1-5]. Due to the nature of quadrupolar moments, sodium spins interact strongly with the electric field gradients of their surroundings, resulting in very short relaxation times and more complex relaxation behaviors in biological tissues (with mono-exponential T_1 and bi-exponential T_2) compared to most protons [6]. Measuring sodium relaxation times in specific tissues is desired for accurately estimating tissue sodium content (TSC) using practical imaging sequences. Due to the lower NMR sensitivity, lower concentrations and rapid signal decay, sodium MRI has a much lower (about 3,000 – 20,000 times) SNR than that of proton MRI [7]. To capture as much signal as possible, dedicated MRI sequences, such as UTE (ultrashort echo time) or TPI (twisted projection imaging) [2, 8] are often employed. However, these techniques may not be available on a clinical scanner and are prone to image artifacts. In this study, we evaluate a more practical approach using only commonly available GRE techniques for *in vivo* sodium T_1 and T_2 measurements. We found that for certain body parts where large slice thicknesses are allowable without introducing much partial volume effects (such as axial calf imaging), an optimized GRE sequence is capable of measuring sodium relaxation times that in turn can be used to calibrate and correct imaging estimates of tissue sodium levels.

Methods: Two healthy volunteers (ages 25 and 37) participated in this study. Experiments were performed on a Philips 3T Achieva scanner (Philips Healthcare, Cleveland OH, USA) with a Rapid sodium quadrature knee coil (Rapid Biomedical GmbH, Rimpar, Germany). Four calibration phantoms (NaCl aqueous solutions with [Na]: 10mM, 20mM, 30mM, and 40mM) serving as calibration standards were scanned together with sections through subject calf muscles. For T_1 measurements, a 2D spoiled GRE sequence was employed with FOV= 192×192mm^2, slice thickness = 40mm, bandwidth = 434Hz/pixel. Five scans with different TRs [=20ms, 40ms, 60ms, 80ms, 100ms] were performed with TE = 1.05ms and flip angle = 90°, each scan took 10-15 minutes by adjusting the numbers of acquisitions. Finally data were fit to a mono-exponential function to compute T_1. For T_2 measurements, a 2D multi-echo GRE sequence was used, with the same geometry as the T_1 scan, other parameters: echo# = 8, TE/ΔTE = 1.19ms/3.3ms, TR = 80ms, FA = 90°, bandwidth = 791Hz/pixel, signal acquisitions = 240, resulting in a scan time of 20min29sec. Data were processed off-line by fitting to a bi-exponential model, so short and long T_2 components were estimated. All fitting was performed pixel-wise.

Results: Figures 1 shows sodium images of sections through the legs of one volunteer at different TR, along with the fitted T_1 recovery curve for one pixel and histogram of T_1 values obtained. For this case, the measured median muscle $T_{1_calf} \approx 15.1$ms. As a comparison, the T_1 in the calibration phantoms was $T_{1_phantom} \approx 27.3$ms.

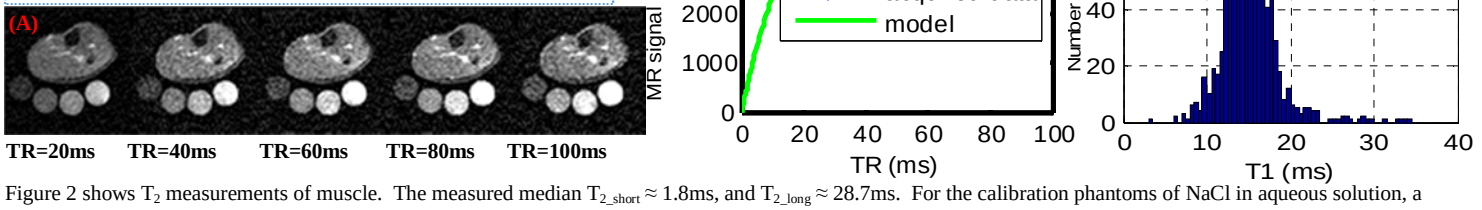

Figure 1. (A) Sodium images of human calf at different TRs used for T_1 measurement. The calibration phantoms are shown at the bottom of the image: left to right corresponds to [Na] of 10mM, 20mM, 30mM, and 40mM. (B) An example of the mono-exponential T_1 fitting from a calf pixel, and (C) A histogram showing the sodium T_1 distribution in calf.

Figure 2 shows T_2 measurements of muscle. The measured median $T_{2_short} \approx 1.8$ms, and $T_{2_long} \approx 28.7$ms. For the calibration phantoms of NaCl in aqueous solution, a mono-exponential T_2 relaxation should hold, and the measured $T_{2_phantom} \approx 23.8$ms.

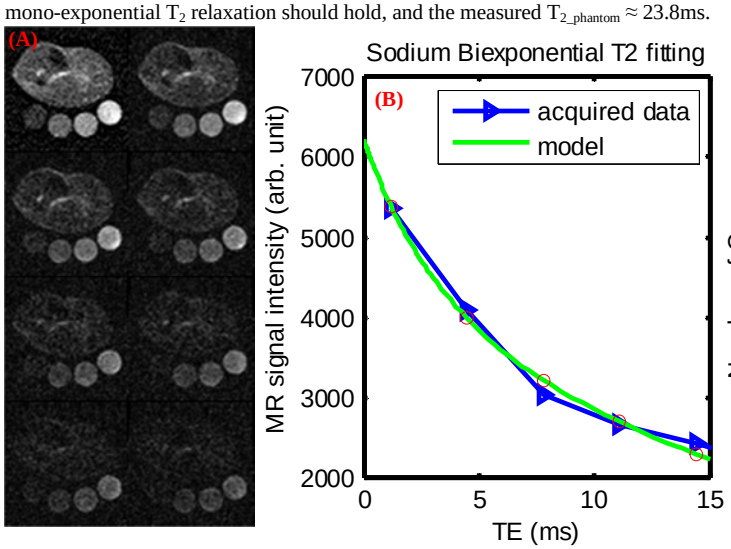

Figure 2. (A) Sodium images at different echoes for T_2 measurement. (B) An example of the bi-exponential T_2 fitting from a pixel in calf region, and (C) T_2 distribution (histogram) in calf. Upper panel: short T_2 component, and lower panel: long T_2 component.

Discussion: Knowing the relative values of sodium T_1 and T_2 in tissues and phantoms is important for accurately calibrating and correcting estimates of tissue sodium levels made from images. The measured sodium T_1 and T_2 in our study are consistent with literature reported values in muscle [7], which indicates the feasibility of accurate *in vivo* sodium T_1 and T_2 measurements using optimized (and commonly available) GRE sequences.

References: [1] Ouwerkerk *et al*. JACC 2007; 4:739. [2] Boada *et al*. MRM 1997; 37:706. [3] Ouwerkerk *et al*. Radiology 2003; 227:529-37. [4] Constantinides *et al*. Radiology 2000; 216:559. [5] Kopp *et al*. Hypertension 2012; 59:167. [6] Madelin *et al*. Sci Rep 2014; 4:4763. [7] Madelin *et al*. JMRI 2013; 38:511. [8] Lu *et al*. MRM 2010; 63:1583.