Sodium Concentration Quantification in Human Calf Muscle Using UTE Imaging at 7.0T

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Introduction:

Sodium metabolism is an important determinant in understanding hypertension [1, 2]. In hypertensive animal models, sodium content is increased in muscle tissue by 38% and in skin tissue by 16% [2, 3]. In humans, sodium-MRI offers the potential to be an ideal candidate for measuring tissue sodium concentrations ([Na]) in the clinical setting. Previous ^{23}Na MRI studies have been able to detect muscular sodium channel diseases at 3.0 T [4]. To reduce the scan time commonly used at 3.0 T or to enhance the spatial resolution of ^{23}Na acquisitions, ultrahigh field MRI can be beneficial due to the signal-to-noise ratio advantage. The biexponential ^{23}Na T_2* decay of muscle tissue which includes a rapidly decaying component with T_2*<0.5 ms requires the use of ultra short echo times. For all these reasons it is conceptually appealing to perform ^{23}Na MRI at 7.0 T in conjunction with a dedicated transceiver RF coil and ultrashort TE imaging for the pursuit of sodium concentration quantification of the human calf muscle.

Methods:

Healthy volunteers were examined on a 7.0 T whole body MR system (Magnetom, Siemens Medical Solutions, Erlangen, Germany). ^{23}Na MRI was performed using a 3D spiral sequence [5] which facilitates ultra-short TE (UTE, Siemens, total acquisition time=3.5 min, TR=100 ms, FOV=(320mm)^2, 5 mm isovoxel, 6 axial slices, number of averages=1) and a gradient echo sequence covering the long TE range (2D FLASH, total acquisitions time=3.5 min, TR=100ms, FOV=192mm, (3x3x30) mm^3). For T_2* mapping a series of images was acquired with T_2*-weighting equally spaced between TE 0.05-0.6ms to cover the ultra-short TE range and with TE set to TE= 2-32 ms to cover the slowly decaying component using 2D FLASH, A monoresonant transmit receive circular polarized sodium coil tailored to the geometry of the human calf (78.60 MHz, Stark Contrast, Erlangen) was used for acquisition covering axial slices of the lower left leg. Tissue [Na] was calibrated by an analysis that compares the signal intensity derived from *in vivo* acquisitions with that of a reference standard consisting of 10mM, 20mM, 30mM and 40mM NaCl solutions. TE dependent signal decay from muscle and 30mM NaCl was fit to a biexponential decay to obtain slowly decaying and rapidly decaying T_2^* human calf muscle tissue components. A 3D flip angle (FA) map has been acquired on a spherical water phantom which fits the size of the RF coil and which was filled with a sodium solution [Na]=50mM for characterization of the coil, using a B_1 mapping method [6] adapted to sodium MRI at 7T.

Results:

For the NaCl-phantom a monoexponential relaxation time of T_2^* = (14.5 ± 0.4) ms was observed. Human calf muscle tissue showed a T_2^*= (1.1 ± 0.1) ms for the rapidly decaying component and T_2^*=(11.6 ± 0.4) ms for the slowly decaying ^{23}Na fraction. With regression of the data to TE=0 ms a sodium concentration $[Na]_{muscle}$= (26 ± 5) mM was found for human calf muscle tissue. The accuracy of the sodium quantification was enabled by using ultrashort echo time imaging since the relative signal loss in muscle tissue is only 2% when moving from TE=0 to TE=50 µs. The FA map acquired on phantom showed that the B_1 distribution is fairly homogeneous and therefore signal intensities are a reliable quantification tool, without the need for corrections.

Conclusion and discussion:

3D spiral UTE imaging at 7T facilitated the quantification of the sodium concentration of the slowly decaying [Na] component in human calf muscle tissue. Since an accurate quantification of sodium concentration should account for all sources of signal variations, this work started to incorporate B_1 sensitivity measurements by using effective flip angle maps. Also partial saturation effects should be corrected with the factor: 1-exp(-TR/T_1) to account for the differences in T_1 between muscle tissue and Na solutions. However these variations are expected to be almost negligible according to previous reports [7]. T_1- and B_1 *in vivo* mapping will be object of future investigations. This state-of-affairs enables us to study sodium metabolism in humans at fast acquisition times.

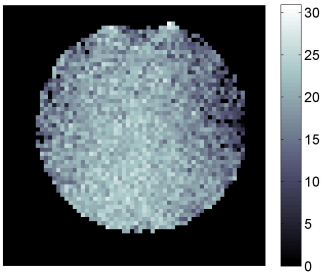

Fig. 1: Flip angle map of the ^{23}Na coil on a 50mM [Na] water phantom. The flip angle is homogeneous in the bottom part of the coil, justifying the absence of signal intensity corrections for this study.

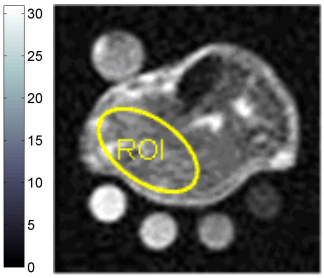

Fig. 2:^{23}Na-image (FLASH-2D, TE = 2 ms) from the lower leg, including 10, 20, 30, 40mM NaCl (+30mM large bottle at the top) to calibrate [Na] in the ROI of the gastrocnemius muscle by linear fit of the signal intensity.

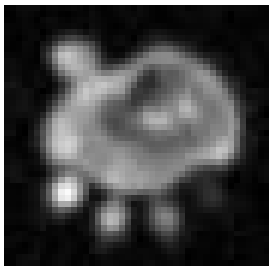

Fig. 3:^{23}Na-UTE-image (TE= 50 µs) at the same region as in Fig. 2, but with 5/3 voxel size to increase SNR. By trend analysis, the [Na] at 50 µs can be calculated to be 25 ± 5 mM which fits well with values from the literature [7].

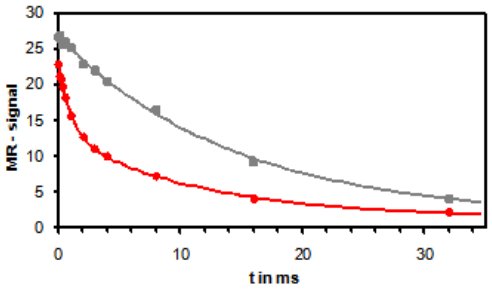

Fig. 4: Biexponential fit of signal-decay at 7T in 30mM NaCl (gray boxes and line) and muscle tissue (red circles and line) calculated from 11 images at different TE. Fits from UTE and FLASH images were calibrated to an equal signal intensity at 1 ms.

References:

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