Quantitative Sodium MR Imaging of the Human Brain at 3.0T

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Introduction

Quantitative tissue sodium concentration (TSC) provides an effective and direct measure of tissue viability based on sodium ion homeostasis [1]. An accurate assessment of viability helps clinicians tailor stroke management decisions to specific patients, to improve clinical outcome [1]. Twisted Projection Imaging (TPI) has been demonstrated to be an efficient 3D MRI technique for whole-brain sodium imaging [2]. In addition, the short T_2, low gyromagnetic ratio, and low *in vivo* TSC make higher field strengths desirable to improve sensitivity of sodium imaging. As 3.0T systems become increasingly common at clinical settings, it is important to ascertain whether the range of TSC measured in healthy adults at this field strength agrees with established literature values.

Methods

Five healthy male adults (age: 28 to 51, avg. 37) underwent this Institutional Review Board approved study. The 3.0T measurements were performed on a whole-body long-bore MR scanner equipped with broad band circuitry (Signa EXCITE HD, GE Healthcare, Waukesha WI, USA). The RF coil used was a custom-made TEM, transmit/receive, head coil tuned to the sodium frequency at 3.0T (33.8MHz). In the TPI acquisition, TE was minimized by using a non-selective 500μs hard RF pulse. Together with post-RF system delays, the experimental TE as measured on an oscilloscope at the output of the gradient amplifiers was 360μs. Other parameters used were similar to those proposed in the original paper [2]: TR=120ms, radial fraction=0.3, 1.6mT/m gradient strength, nominal isotropic resolution of 4×4×4 mm^3 (0.064cc), FOV=26cm, and 4 averages, resulting in a total scan time of 8.8min. Two calibration tubes (30mM and 90mM, T_1=37ms) were placed within the FOV, allowing quantification of the sodium signal as a voxel-wise concentration. The long TR was chosen to minimize T_1 saturation (*in vivo* T_1~10-30ms [3]) while the short TE minimized T_2 signal loss (*in vivo* T_2 (short-component)<3ms), allowing more accurate quantifications [4]. Reconstruction and quantification were performed offline using an inhouse regridding and fitting program written with the IDL software (Research Systems, Inc., Boulder CO, USA).

Results

Fig 1a shows three representative, consecutive, axial sodium partitions from the 3D dataset at 3.0T, for a 28 y.o. volunteer. Fig 1b shows the corresponding TSC maps. Table 1 shows the measured TSC in various brain regions – averaging the four cortex regions' values from both hemispheres gives an average gray matter TSC of 39.1±2.6 mM; averaging the values from forceps major, forceps minor, corona radiata and centrum semiovale from both hemispheres gives an average white matter TSC of 33.3±2.0 mM.

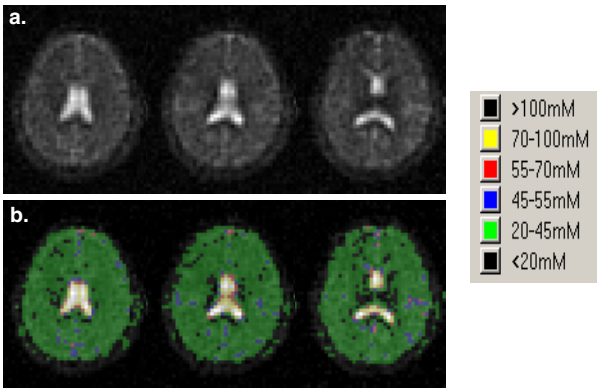

Fig 1 (a) Three representative axial sodium images from the 3D dataset, and (b) corresponding TSC maps, for a 28 y.o. male volunteer at 3.0T.

	TSC at 3.0T* (mM)	
	Right	**Left**
Frontal Cortex	36.2 ± 3.1	36.8 ± 1.8
Parietal Cortex	39.6 ± 1.3	41.4 ± 2.2
Temporal Cortex	41.8 ± 2.8	42.2 ± 2.0
Occipital Cortex	39.4 ± 1.9	35.6 ± 1.8
Forceps Major	37.0 ± 1.6	35.8 ± 2.9
Forceps Minor	33.0 ± 1.9	33.0 ± 2.2
Corona Radiata	32.0 ± 1.6	31.6 ± 2.6
Centrum Semiovale	32.2 ± 0.8	31.8 ± 0.8
Thalamus	31.0 ± 2.9	30.8 ± 2.2
Basal Ganglia	31.0 ± 1.6	32.2 ± 2.2

Table 1 Tissue sodium concentrations for various brain regions measured at 3.0T (*averaged over 5 volunteers), at a nominal 4×4×4 mm^3 resolution

Discussion

The relatively low resonance frequency of sodium (33.8MHz vs. 127.7MHz for proton, at 3.0T) means that sodium imaging does not suffer nearly as much from the dielectric resonance effects as proton imaging does at higher field strengths. This enables accurate TSC measurements without the need of acquiring a B_1-map at 3.0T - our measured TSC values agree with those reported in previous studies [1,5]. However, interestingly, the TSC values reported in ref. [3] at 1.5T (61±8 mM in gray matter, 69±10 mM in white matter) were much higher than our values. We hypothesize that the increased SNR at 3.0T realizes an improved spatial resolution over the nominal prescribed resolution, thus reducing partial volume effects from the high signals from cerebrospinal fluid, resulting in more accurate TSC values.

Conclusion

We have shown that accurate TSC can be measured in human brains at the increasingly available clinical high field strength of 3.0T in <9min, paving the way to routine clinical quantitative sodium imaging at clinically-useful resolution and scan time.

References: 1. K.R. Thulborn, *et al.,* Radiology **213**, 156 (1999); 2. F.E. Boada, *et al.*, MRM **37**, 706 (1997); 3. R. Ouwerkerk, *et al.*, Radiology **227**, 529 (2003); 4. F.E. Boada, *et al.*, MRM **32**, 219 (1994); 5. J.D. Christensen, *et al.*, MRM **36**, 83 (1996).

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