Regional variation of total sodium concentration in the healthy human brain

Ferran Prados[1,2], Bhavana S Solanky[2], Patricia Alves Da Mota[2], Manuel Jorge Cardoso[1], Wallace J Brownlee[2], Frank Riemer[3], David H Miller[2], Xavier Golay[4], Sebastien Ourselin[1], and Claudia Angela Michela Gandini Wheeler-Kingshott[2,5]

[1]Translational Imaging Group, Medical Physics and Biomedical Engineering, University College London, London, United Kingdom, [2]NMR Research Unit, Queen Square MS Centre, Department of Neuroinflammation, UCL Institute of Neurology, University College London, London, United Kingdom, [3]Department of Radiology, University of Cambridge, Cambridge, United Kingdom, [4]Brain Repair & Rehabilitation, UCL Institute of Neurology, University College London, London, United Kingdom, [5]Brain Connectivity Center, C. Mondino National Neurological Institute, Pavia, Italy

Synopsis

Non-invasive measurement of in vivo total sodium concentration (TSC) has been possible due to advances in sodium MRI at clinical field strengths. Changes in white and grey matter concentrations have been reported in a number of different diseases like Multiple Sclerosis. However, the presence of regional differences in normal healthy brain TSC has not been yet investigated. Here we use Geodesic Information Flow technique for computing per subject brain parcellations to allow differentiation of these areas and subsequently characterization of regional TSC in healthy controls.

Introduction

Non-invasive measurement of in vivo total sodium concentration (TSC) has been possible due to advances in sodium MRI at clinical field strengths. Changes in white matter (WM) and grey matter (GM) concentrations have been reported in a number of different diseases like, Multiple Sclerosis (MS). However, the presence of regional differences in normal healthy brain TSC has not been yet investigated. Here we use Geodesic Information Flow[1] (GIF) technique for computing per subject brain parcellations to allow differentiation of these areas and subsequently characterization of regional TSC in healthy controls.

Methods

Sodium Protocol: 10 healthy controls were scanned on a 3T Philips Achieva and underwent two protocols in the same session using: a 32-channel head coil and a fixed tuned sodium volume coil (Rapid Biomedical). The first protocol was composed of PD/T2 (1x1x3 mm^3) and 3DT1-weighted (1x1x1 mm^3) MRI. The second 23Na-MRI protocol was a 3D-Cones UTE sequence[2] (3x3x3 mm^3) (see Figure 1) and a 1H PD/T2w (1x1x3 mm^3) sequence. Two agar phantoms with 40 and 80 mM NaCl were placed either side of the head for quantification.

Processing: Probabilistic brain tissue segmentation was performed on the 3DT1 images using GIF (see Figure 2). The segmentation masks were registered to the TSC maps. To preserve mask integrity, masks were resampled to sodium space using a point-spread function[3] with a linear interpolation. The resample step was performed using the concatenation of three affine transformations from the registrations of: 3DT1 to the pseudo-T1 images (PDw-T2w images[4]), the T2w to the 1H PD/T2w images, and finally 1H PD-T2w image to the TSC map.

Partial volume correction: With the aim to remove the CSF sodium contribution in the brain tissues, we applied a voxel-by-voxel modified partition-based subject-specific correction[5]. The average TSC for the voxels with 100% probability of being CSF were computed. Then the final tissue sodium concentration was expressed as $C_{tissue} = \frac{(C_{voxel} - C_{CSF} * VF_{CSF})}{VF_{tissue}}$ where C represents TSC and VF is the volume fraction provided by GIF. As in Paling et al., only voxels with at least 20% tissue VF were included to produce a mask threshold to 0.2 for each area. In order to reject unrealistically high TSC values, a threshold was set to 2 standard deviations above the mean of the TSC in voxels with at least 95% of tissue probability ($TSC_{mean\_95\%}$). This was used as an additional threshold so that only voxels within the 0.2 threshold mask, which also had TSC values within two standard deviations of the $TSC_{mean\_95\%}$, were included.

Selected brain areas: We selected and compared the following brain areas from both the left and right hemispheres: *Frontal Lobe*, *Occiptal Lobe*, *Sensorimotor Cortex*, *Hippocampus*, *Limbic System*, *Thalamus*, *Cerebral White Matter*, *Brainstem*, *Cerebellum White Matter*, *Cerebellum Grey Matter* and *Cerebellar Vermis*. Following this the *Sensorimotor Cortex* area was split into two groups depending on whether the subjects were left or right handed.

Results and Discussion

Table 1 shows the sodium concentration per brain tissue type, and Table 2 per brain area. Most of the brain regions have similar concentrations in both hemispheres and differences are not significant. Only the *Occipital Lobe* (visual areas) has significant differences between hemispheres. The *Sensorimotor Cortex* for left handed subjects has significant differences from the TSC of right-handed subjects, but this could be due to the lower sample size. All left handed subjects have less sodium concentration in the right hemisphere and vice versa with right handed subjects.

Conclusions

We have presented the first regional sodium concentration study in human healthy brain. Future work will analyse a larger cohort and will explore the correlation with clinical scales for different diseases.

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References

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Figures

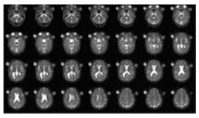

Figure 1: raw sodium image example

Figure 2: 3D T1 image and the coloured parcellation obtained from GIF, computed at http://cmictig.cs.ucl.ac.uk/niftyweb

10 Subjects	Avg	Std
GM	40.06	2.97
CGM	40.97	3.12
DGM	34.39	2.73
WM	31.31	3.92

Table 1: Sodium concentration per brain tissue

10 Subjects	Left		Right		paired
	Avg	Std	Avg	Std	t-test
Frontal Lobe	36.67	3.16	37.20	5.22	0.79
Occipital Lobe	38.80	2.79	34.95	4.40	0.03
Sensorimotor Cortex (LH)	35.76	1.35	23.10	9.81	0.04
Sensorimotor Cortex (RH)	24.86	8.65	33.03	13.81	0.25
Hippocampus	47.10	4.59	44.78	5.23	0.30
Limbic System	47.16	2.87	43.80	4.45	0.06
Thalamus	33.38	1.98	36.21	6.27	0.19
Cerebral WM	31.58	3.79	30.93	4.21	0.72
Cerebellum WM	29.77	2.88	28.15	4.32	0.34
Cerebellum GM	34.14	4.04	35.38	4.57	0.53
	Avg		Std		
Brainstem	34.44		3.68		
Cerebellar Vermis	45.38		5.37		

Table 2: Sodium concentration per brain area and hemisphere side. Mean and standard deviation are provided. Sensorimotor Cortex has been split in left and right hand side subjects (3 subjects LH, 7 subjects RH). Last column shows paired t-test between hemispheres.