^{31}P MR Spectroscopic Imaging of the Human Brain at 7 T with Nuclear Overhauser Enhancement

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Target Audience: Neuroscientists, Neurologists, Psychiatrists, Spectroscopists

Purpose

Phosphorus spectroscopy provides information on molecules involved in both energy and phospholipid metabolism in the brain with signals from phosphocreatine (PCr), inorganic phosphate (Pi), and ATPs and from (glycero-)phosphoethanolamine (G)PE and (glycero-)phosphocholine (G)PC), respectively. The promise of high field ^{31}P MRS is to attain this information with a spatial resolution and SNR that is clinically useful. Most human brain 7T ^{31}P MRS studies have been performed with transmit/receive surface coils detecting signals from the occipital lobe [1-3]. For many neurological and psychiatric diseases, signals from different deep brain structures are of interest, requiring 3D ^{31}P MRS of the whole brain with a volume coil. Next to a dual-tuned TEM coil design used to quantify energy expenditure of the human brain at 7T [4,5], a dual birdcage coil has been designed with the possibility to manipulate ^{1}H frequencies during the ^{31}P examination, enabling the use of Nuclear Overhauser Enhancement (NOE) to increase the SNR of the ^{31}P metabolites. In this work, we compared different NOE strategies in phantoms and quantified NOE in deep brain areas of five healthy volunteers.

Methods

A dual-coil assembly of a ^{1}H and a ^{31}P CP birdcage coil (Quality Electrodynamic LLC, Mayfield Village, Ohio, USA), was used to transmit and receive the ^{1}H and ^{31}P signals on an active-shielded 7T whole body MR system (Magnetom 7T, Siemens Healthcare, Erlangen). To assess a proper NOE strategy, adapted from low-power decoupling schemes [6], ^{31}P MRSI of a phantom with a PE and PC solution was measured with and without ^{1}H irradiation. The NOE waveforms consisted of either continuous wave irradiation with constant phase or continuous wave with 1-ms random phase jumps, both performed on-resonance (at water) as well as 100 Hz off-resonance. NOE enhancement was assessed by normalizing peak integrals to the resonance peaks without NOE.

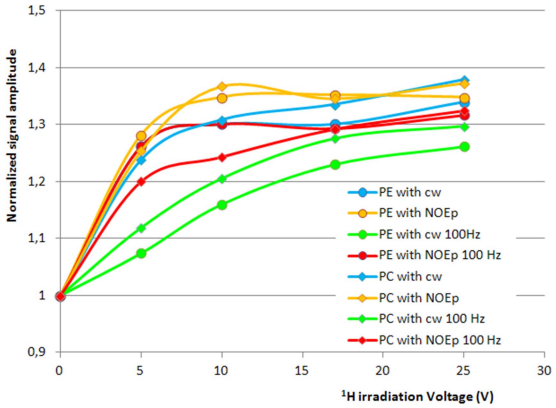

***Figure 1**. Signal increase of PE and PC due to NOE.*

Furthermore, five healthy volunteers were examined with the dual coil. After quick localizer images, anatomical imaging was performed using MPRAGE with 1mm isotropic resolution. For each volunteer, the ^{31}P RF power level was calibrated by searching FID null signal from a 30 mm thick axial slice through the brain at varying flip angles. To evaluate NOE, two identical 3D ^{31}P MRSI acquisitions were obtained: one without and one with NOE (near-continuous irradiation at γB_1~40Hz with 1-ms randomized phase during TR, consuming 25% of allowed SAR). Other parameters: TR=1.55 s, flip angle=45˚, FOV=220 x 220 x 220 mm^3, matrix=10 x 10 x 10, weighted elliptical k-space acquisition and filtering resulting in 31 cc voxel size, scan time=9 min). Next to this, 3D ^{31}P MRSI with a higher spatial resolution of 10.6 cc (FOV=200 x 180 x 180 mm^3, matrix=12 x 12 x 12) was acquired with NOE (scan time=21 min). For each volunteer, the spectra of one voxel in the pons, right anterior horn, left putamen, and left white matter were selected and fitted with complex Gaussian line-shapes, including a baseline (metabolite report, Siemens Healthcare). Signal enhancement due to NOE was quantified as the relative increase in fitted signal integral for every metabolite. After fitting the MRSI acquisition with NOE, metabolite maps were constructed from the integrals of the fitted metabolites.

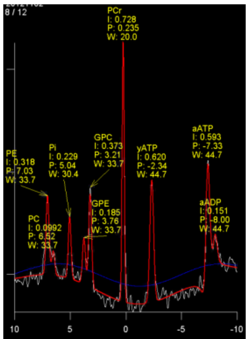

***Figure 3**. Complex fit to all ^{31}P metabolites with baseline*

Results

When irradiated on-resonance, the effects of the phase of the NOE pulse shape were small (Fig.1): enhancement was very similar (~35% for PE and PC) for constant phase versus 1-ms random phase jumps (NOEp). At 100 Hz from water, NOEp resulted in higher enhancement than constant phase NOE for equal irradiation voltage, and the maximum enhancement (~32% for PE and PC) for NOEp was reached at a voltage ~20 V. This voltage was used in all volunteers (γB_1~40 Hz) and enhanced ^{31}P signals across the brain. Generally, this enhancement, quantified by complex fitting (Fig.3), enhanced phospholipids more than Pi, PCr and ATPs, but showed some variation for different deep brain tissues (Table 1). The 10.6 cc ^{31}P-MRSI acquisition provided detailed information on ^{31}P metabolites of nearly the whole brain (Fig. 4), with PCr linewidths below 20Hz in many areas.

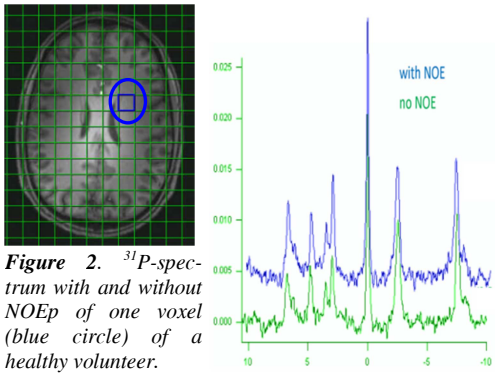

***Figure 2**. ^{31}P-spectrum with and without NOEp of one voxel (blue circle) of a healthy volunteer.*

Discussion and Conclusion

The ^{1}H-^{31}P dual-birdcage coil enabled NOE enhancement across the brain.

	PE	PC	Pi	GPE	GPC	PCr	γATP	αATP
pons	20	42	28	21	16	17	8	19
putamen	37	49	23	46	40	23	12	10
horn	26	5	25	46	32	19	12	7
WM	34	59	23	38	32	21	13	5
total mean	29	38	25	38	30	20	12	10
total SD	17	37	25	33	20	7	6	9

***Table 1**. NOE enhancement for different signals in different deep brain structures, and the total mean NOE for all signals.*

The 21-minute acquisition with NOE provided good SNR. PE, PC, GPE and GPC were resolved. Metabolite maps of the individual resonances can give insight into their spatial distribution. Both B_0 and ^{1}H B_1 field inhomogeneities at 7T could have contributed to the observed variations in NOE, which could be assessed with B_0 and ^{1}H B_1 fieldmaps. Other NOE strategies (e.g. WALTZ4) need to be compared for NOE enhancement stability. The β-ATP resonance (not shown) was lower in intensity due to limitations in the bandwidth of the excitation pulse. We have successfully implemented 3D ^{31}P-MRSI with NOE on an active-shielded 7T scanner, providing a tool for deep brain ^{31}P MRS for neurological and psychiatric disease studies.

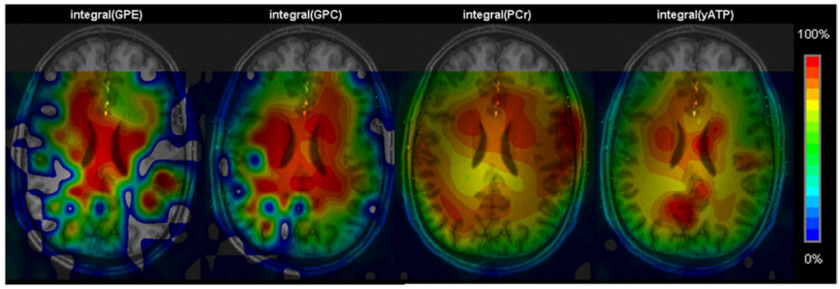

***Figure 4**.Metabolite maps of GPE, GPC, PCr and γATP of one partition of 3D ^{31}P-MRSI.*

References [1] Chen et al MRM 49:199 (2003); [2] Chen et al MRM 57:103 (2007); [3]Wijnen et al, ISMRM proceedings 377 (2010); [4] Chen et al Neuroimage 60:2107 (2012); [5] Sammi et al, ISMRM proceedings 1805 (2012); [6] Li et al MRM 57;265 (2007)