High resolution ^{31}P Magnetic Resonance Spectroscopic Imaging of the human brain at 7T.

J. P. Wijnen[1], A. Heerschap[1], and T. W. Scheenen[1,2]
[1]Radiology, Radboud University Nijmegen Medical Centre, Nijmegen, Gelderland, Netherlands, [2]Erwin L. Hahn Institute for Magnetic Resonance Imaging, Essen, Germany

Introduction:
Tissue levels of different phosphorylated compounds in the human brain can be investigated in vivo with ^{31}P Magnetic Resonance Spectroscopy. Despite the use of higher field strengths (<4T) and long acquisition times the spatial resolution of ^{31}P MR Spectroscopic Imaging remains rather low [1]. With the introduction of whole body 7T MR systems ^{31}P spectroscopic imaging can now be performed with clinically relevant spatial and temporal resolution. In this work we present the use of a quadrature ^{31}P surface coil at 7T, which can be inserted into a ^{1}H birdcage coil to evaluate local spatial differences in MR-visible phosphorus compounds in the human brain. The spatial resolution attainable at 7T with ^{31}P MRSI within clinically acceptable acquisition times becomes close to what is commonly used for ^{1}H MRSI at 3T.
Aim: To maximize the spatial resolution of ^{31}P MRSI in the human brain at 7 Tesla with a clinically feasible set-up.

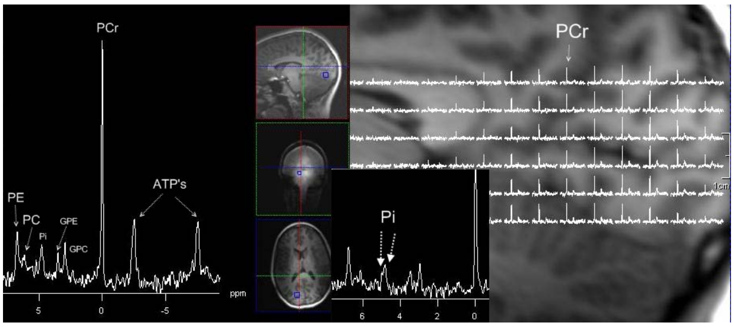

Figure 1: ^{31}P MR spectrum of white matter and a spectral map in saggital direction overlaid on a T1 weighted image. Both images were obtained from a measurement of 16 min with a resolution of 6.3cc. Signals from the membrane as well as the energy metabolism are clearly visible and well separated.

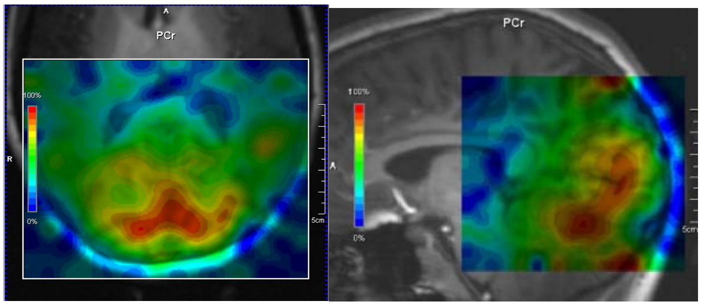

Figure 2: Metabolite maps of PCr in the transverse and saggital plane in the measurements with high resolution (1.7cc). The B1 coil profile of the ^{31}P surface soil is well recognisable.

Methods:
A circularly polarized birdcage ^{1}H head coil was combined with an in-house developed double loop quadrature ^{31}P surface coil (inserted in the head coil), covering the parietal and occipital lobe. Examinations were performed on 3 healthy volunteers at a Siemens 7T MR system. As an anatomical reference image set, 3D T1-weighted (magnetization preparation by inversion) images were acquired, with 1.3mm isotropic voxels, IT=1100ms, TR=2000ms TE=1.1ms, acquisition time 4.48 minutes. Subsequently, ^{31}P MRSI was run with a pulse acquire spectroscopic imaging sequence with a 8ms (BW 1800Hz) adiabatic excitation RF pulse (BIR-4) with a flip angle of 45 degrees, allowing for a short repetition time of 1500ms. Shimming of the region of interest was performed by a supervised automated 3D mapshim algorithm. Two ^{31}P MRSI measurements were performed. A high resolution ^{31}P MRSI of phosphocreatine (PCr) and γ-ATP only with a real voxel size of 1.7cc was obtained within 24 minutes, with the carrier frequency of the adiabatic excitation pulse positioned at the frequency of PCr. Additionally, a ^{31}P MRSI of the phosphomono and diester (PME and PDE) resonances in the brain was obtained with somewhat lower resolution (real voxel size of 6.3cc) within an acquisition time of 16 minutes. In these measurements the carrier frequency was positioned at the frequency of inorganic phosphate (Pi). The field of view, number of acquisition weighted averages and the matrix size were adapted to obtain the desired resolution within the targeted acquisition time (24 minutes for PCr and γ-ATP, 16 minutes for PME and PDE). MR spectra were fitted with Siemens Syngo software and metabolite maps were overlaid on a T1-weighted background image.

Results and Discussion:
In the MR spectra, the resonances of phosphoethanolamine (PE), phosphocholine (PC), inorganic phosphate (Pi), glycerophosphoethanolamine (GPE) and glycerophosphocholine (GPC) were well separated and had high SNR in the measurements with voxel sizes of 6.3cc (Fig.1). In these spectra also clear signal from PCr and γ-ATP could be observed. The α-ATP signal was attenuated by sub-optimal excitation at the limit of the bandwidth of the excitation pulse and the β-ATP signal was not visible at all. In some voxels of the brain a double Pi resonance could be observed, indicating the presence of two separate water fractions with different pH. In the high-resolution measurement of PCr and γ-ATP (voxel sizes of 1.7cc) the signals of PME and PDE as well as α-ATP and β-ATP were not visible (with few exceptions in the most sensitive spot of the ^{31}P coil) due to too low SNR in these small volumes.
The metabolite map of PCr reveals the local distribution of PCr signals and the B1 reception profile of the ^{31}P surface coil (Fig.2). Signals with sufficient SNR can be obtained from a large part of the parietal/occipital part of the brain. Outside the brain the signal intensity is zero as well as in the ventricles. From the corpus callosum the signal intensity decreases rapidly when looking at voxels at more frontal locations. Furthermore, the PCr distribution is symmetric in the left and right side of the brain. Since ratios of metabolites are independent of the B1 coil profile, a color map of these can reveal differences in metabolite level between tissue types. Maps of PE/GPE and PE/GPE+GPC show differences between white and gray matter of the brain (Fig.3).

Conclusion:
We demonstrated a ^{31}P MRSI technique to detect phosphorylated signals in the human brain at 7T with high sensitivity and spatial resolution within relatively short acquisition times (16 or 25minutes). The spatial distribution of phosphomono and diesters as well as PCr and γ-ATP can be studied with high sensitivity. This enables to study the phosphorylated energy metabolism and the composition of phosphomono and diesters in human brain diseases in a clinical setting.

References: [1] Hetherington, MRM, 2001:45, p46

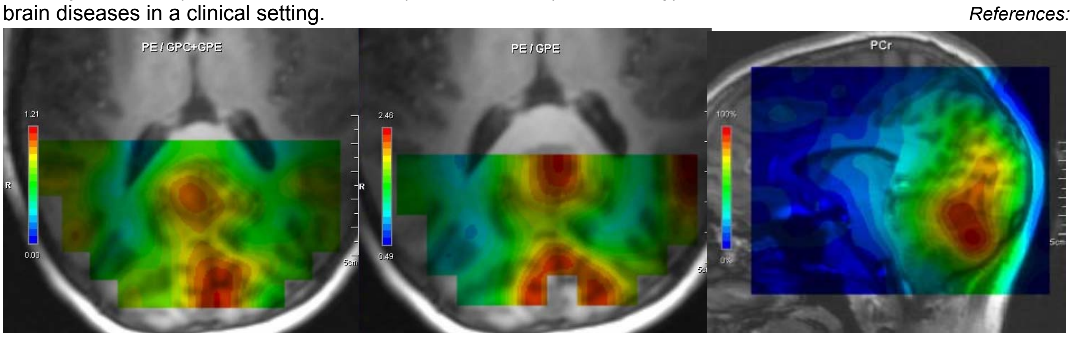

Figure 3: Metabolite maps of PE/GPE+GPC (left), PE/GPE (middle) and PCr (right) in the ^{31}P MRSI measurements with resolution of 6.3cc. Differences in phopshoesters between white and gray matter become best visible in the PE/GPE+GPC map. PCr was also present in a large part of the brain in the measurements with a resolution of 6.3cc.