Phosphorus 3D CSI at 9.4 T using a 27-channel Receiver array

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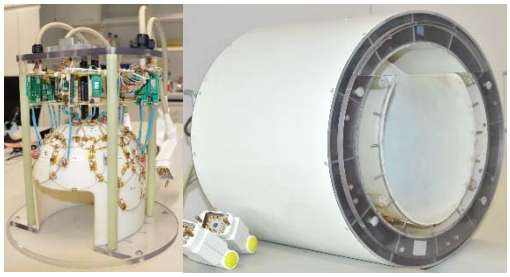


FIG.1. 27-channel ^{31}P receiver array (left) and fully assembled coil arrangement (right).

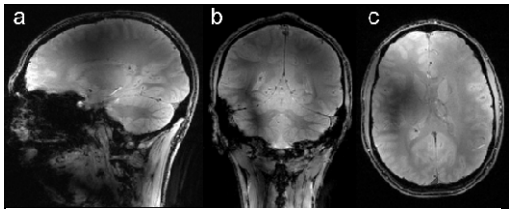
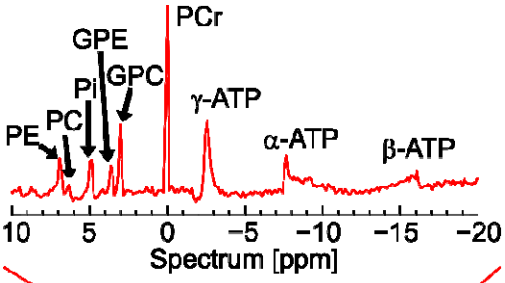


FIG.2. Sagittal (a), coronal (b), and transversal gradient echo images acquired with the 4-channel dipole array.



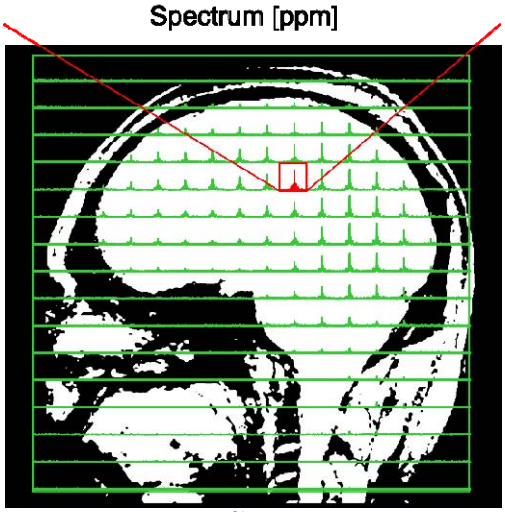


FIG.3. Spectra from the ^{31}P CSI measurement.

Target audience: RF engineers, ultra-high field (UHF) MRI and 31P MRS researchers.

Purpose: Phosphorus spectroscopy and X-nucleus imaging in general benefit greatly from the increased signal-to-noise ratio (SNR) available at ultra-high field strength. The SNR can be enhanced even further by using tightly fitting multi-channel receiver arrays. In this work, a three-layered coil arrangement, originally proposed for ^{23}Na MRI at 9.4 T[1], was adapted for phosphorus (^{31}P) spectroscopy and proton (^{1}H) imaging to perform ^{31}P 3D chemical shift imaging (CSI) of the human brain at 9.4 T.

Methods: All measurements were performed on a Siemens (Erlangen, Germany) 9.4 T whole-body MRI scanner. The coils were arranged in three layers: The innermost layer consisted of a helmet on which a 27-channel ^{31}P (161.8 MHz) receiver array was constructed (FIG.1). The helmet was fixed inside a four-channel ^{31}P transceive array, which was used for spin excitation. For anatomical localization and B_0 shimming, four inductively shortened dipoles[2] tuned to the proton frequency (399.7 MHz) were placed 2.5 cm above each element of the four-channel ^{31}P array.

The receive coil elements were constructed using 1.6 mm diameter silver coated copper wire and tuned to 161.8 MHz using four capacitors in series. A fuse was incorporated in each loop. The adjacent elements were decoupled using geometric overlap[3]. The coil input was matched to 50 Ω and the phase length of the coaxial cable to the preamplifier was adjusted for preamplifier decoupling[4]. The transceiver coil for ^{31}P consisted of four large loops (15 x 18 cm). The adjacent and non-adjacent loops were inductively decoupled and driven in circularly polarized mode using a combination of three quadrature hybrids which generated four outputs of equal amplitude and 90° phase offset. Receive function was also incorporated in the ^{31}P transmit array by combining the received signal in phase and feeding it to a single receive channel.
At the beginning of each scanning session 2D gradient echo images were acquired in sagittal, coronal, and transversal orientation for anatomical localization. The imaging parameters were chosen as follows: TE 5 ms TR 300 ms, Slices 30, Resolution 1.1x1.1x2.0 mm^3, Bandwidth per Pixel 500 Hz/Px, Acquisition Time (TA) 1 min per orientation. B_0 shimming was performed with the automatic shimming interface of the scanner before the acquisition of the 3D CSI dataset. The matrix size of the CSI acquisition was 8x8x8 and the field of view was 200x200x200 mm^3. Further parameters were: spectral bandwidth 10'000 Hz, 512 samples, hard excitation, pulse duration 0.5 ms. In order to reduce the scanning duration a repetition time of 750 ms and elliptical scanning were used giving a total acquisition time of 13 min. The spectra from the individual coils were combined by the scanner software and interpolated to a 16x16x16 grid before being exported to Matlab in order to perform an off-line phase correction.

Results: The unloaded Q measured on a representative receive loop was 230 and the Q ratio was 4.5. Preamplifier decoupling was better than -22 dB and active detuning in the transmit and receive arrays was less than -30 dB. The proton gradient echo images acquired with the 4-channel dipole array are shown in Figure 2. Further improvements are possible by adjusting the dipoles in the scanner environment. As demonstrated by the coronal and sagittal images a large longitudinal coverage could be achieved. Figure 3 shows the T1-weighted spectrum for one voxel of the CSI dataset. A multitude of ^{31}P metabolites can be discriminated: Phosphoethanolamine (PE), phosphocholine (PC), inorganic phosphate (Pi), glycerophosphoethanolamine (GPE), glycerophosphocholine (GPC), phosphocreatine (PCr) and adenosine triphosphates (ATP).

Discussion: We have shown that the originally proposed three-layered coil design can be successfully adapted to different frequencies. Owing to the high field strength and the sensitive 27-channel receiver array ^{31}P 3D CSI data of the human brain could be acquired in an acceptable time. Due to the short repetition time compare to the longitudinal relaxation time (1-3 s)[5] the spectra cannot be used for quantification as the peak intensities are subject to signal saturation.

References: 1. Shajan et al. Proceedings ISMRM-ESMRMB 2014;22:620. 2. Lakshmanan K et al. Proc. ISMRM 2013 p2754 3. Wiggins G et al. MRM 56:216-223 (2006) 4. Roemer et al. MRM 16: 192-225 (1990), 5. Lei at alMRM 49:199–205 (2003).