A circular-polarized double-tuned (31P and 1H) TEM coil for human head MRI/MRS at 7T

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SYNOPSIS
A double-tuned human head TEM coil is designed for in vivo proton and 31P MR applications at 7T. 3D 31P CSI and high-resolution human head image acquired from the whole brain using this coil are presented. A superior SNR of 91:1 of 31P spectra from 15.5-cc voxels in the human brain is achieved within 18-minute data collection in vivo. The results of in vivo MR experiments and bench test indicate i) excellent performance of this double-tuned large volume coil design for human proton and 31P MR studies; ii) great advantages of 31P MRS at ultra-high fields.

INTRODUCTION
The TEM volume coil was introduced by Vaughan et al originally for human head MR applications at 4T (1)(2). Recent studies further demonstrated the superior performance of the TEM coil design for proton MRI at 7T (3) and 8T (4). In this work, we present a double-tuned, circular-polarized TEM volume coil for human head proton and 31P MRI/MRS studies at 7 Tesla. A much shorter coil length, compared with commonly used single-tuned coil, was applied in this coil design, for restricting coil’s B1 field to the human brain for higher sensitivity of brain 31P spectrum detection.

METHOD
The circular-polarized double-tuned TEM volume coil was built in our lab to operate at 296.05 MHz and 119.85 MHz, Larmor frequencies of proton and 31P at 7T. The method of design and construction of this coil was similar to the previous work (3). 8 resonant elements of proton channel and 8 resonant elements of 31P channel were alternatively positioned in a cylindrical cavity made from 18-µm thick copper foil, with dimensions of 34-cm in diameter and 15.3-cm in length, as indicated in Figure 1. The coil diameter was measured to be 28 cm. The inner conductors of the coaxial resonant elements were 0.64-cm diameter solid copper rods for both proton and 31P channels. Adhesive-backed copper foils (3M, St Paul, MN) with 35µm thickness were directly wrapped on the dielectric material of the struts to simply form the outer conductors of the resonant elements. The diameters of these outer conductors were 1.47-cm for proton channel and 0.84-cm for 31P channel, respectively. For 31P channel, the much thinner dielectric of ~0.1-cm combined with a 30-pF capacitor connected on one end of each resonant element of 31P channel was applied to ensure the desired resonant mode operating at a relatively low frequency of 120 MHz, i.e. Larmor frequency of 31P at 7T. The dielectric materials between the inner conductors and outer conductors for both channels were PTFE that has a low loss property that is important for RF coil designs, especially high frequency coil designs. The coil was built with no end-cap that made the coil friendlier to patients and easy to use. The coil was driven quadraturely with two KDI 3dB-900-hybrids model QH-23 for 1H and QH-21 for 31P, respectively. All MR experiments were performed on a 7T/90cm magnet interfaced to the Varian INOVA console.

RESULTS
The prototype coil as shown in Fig. 2 was optimized for human head proton and 31P studies at 7T. The proton and 31P channels were tuned to 296.05 MHz and 119.85 MHz, respectively. The S21 measurements performed on the network analyzer showed that the isolation between the proton channel and 31P channel was better than –30 dB while isolation between the two quadrature-ports of proton channel was greater than –35 dB and the quadrature port isolation of 31P channel had the same level as that of proton channel. Loaded and unloaded Q measured 195/90 for proton channel at 296.05 MHz and 455/120 for 31P channel at 119.85 MHz. The coil can be easily matched to system 50 Ohm for both proton and 31P channels. Fig.3 shows the experiments with a mineral oil phantom. The results show this circular-polarized coil was well behaved at 296.05 MHz. Fig. 4 shows a high quality T1 weighted human head image acquired using the coil with a slice thickness of 2 mm. In 31P MRS study, an excellent SNR of 91:1 from a 15.5-cc voxel inside human brain was achieved within 18 minutes in vivo, as shown in Fig.5. Such superior sensitivity made it possible to reliably detect a small amount of uridine diphosphate (UDP) resonance in the deepest brain region as shown in Fig 5. The average RF power in a duty cycle used to generate such a 3D 31P chemical shift imaging was 0.05 W/kg with a pulse width of 500 µs.

CONCLUSION
A circular-polarized doubly tuned TEM coil is successfully designed and constructed for human head 1H and 31P MRI/MRS at 7T. Although only 8 struts were used for each channel with a short coil length, the coil still presents an excellent performance for both proton and 31P in human brain studies at 7T. The success of this coil will certainly aid ultra-high field human 31P MRS studies.

REFERENCES

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Fig. 1 A cross-sectional view of the prototype double-tuned TEM coil for human head at 7 Tesla. Both channels were driven quadraturely.

Fig. 2 The circular-polarized double-tuned TEM coil for human head proton and 31P MRI/MRS at 7 Tesla.

Fig. 4 T1 weighted human head proton image acquired using the double-tuned TEM coil. Slice thickness=2mm.

Fig. 3 Proton images acquired from a mineral oil phantom (15-cm dia x 24-cm long) using the double-tuned TEM coil. Signal decrease was observed when an anti-phase drive applied (right insert). TR = 100ms, TE = 4ms, FOV = 25 cm x 25 cm, NEX = 1.

Fig. 5 3D 31P CSI of human brain acquired using the prototype coil at 7T (2D display in axial orientation). Acquisition time was 18.2 minutes. SNR of PCr resonance of central voxels was in a range of 70:1 to 91:1. Voxel size of each spectrum was 15.5 cc. The top insert is an enlarged view of the circled spectrum in the map. UDP was observed in the center of the human head.