Initial experience with 31P Imaging of human brain using a multi-resonance, spectral-selective sequence at 9.4Tesla

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INTRODUCTION

Phosphocreatine (PCr) is a metabolic buffer against fluctuations in cellular ATP. In the brain, PCr concentration reflects ATP demands and production through oxidative metabolism [1-4]. However, due to their low detection sensitivity, quantitative ^{31}P MR signals have been mainly obtained with spectroscopy or chemical shift imaging approaches, which are either time consuming or limited in spatial resolution. Fast imaging techniques such as RARE have also been proposed [5]. However, they often result in relatively high SAR and the obtained signal is a complex function of many parameters such as T2 and the transmission sensitivity. In this work, we report initial ^{31}P imaging results using a modified spectral selective twisted projection imaging (TPI) sequence [6] to achieve high data acquisition efficiency while simplifying the signal interpretation and minimizing SAR. Exploiting the increased detection sensitivity of a 9.4T human scanner, both PCr and γ-ATP images were simultaneously obtained with whole brain coverage at 1.5 cm isotropic resolution in a reasonable scan time. The ratio images can then be calculated to potentially study any variation in PCr concentration as ATP concentration remains relatively constant.

MATERIALS AND METHODS

The long T1 of the phosphate containing metabolites requires a long TR value to avoid magnetization saturation. As there is a wide chemical shift between the metabolite resonances at ultra-high field, a spectrally selective RF pulses can be used to use this recovery time to acquire multiple resonances within one repetition time. For this purpose, we have implemented a multiple echo, multiple resonance MR imaging sequence with a modified twisted projection imaging (TPI) readout to sample k-space efficiently with short echo times (TEs) to also minimize signal loss due to T2 relaxation. The data acquisition scheme used to acquire both the PCr and γ-ATP resonance signals is illustrated in Fig. 1. The γ-ATP resonance has a shorter T1 (~1.2 s) than PCr (>3s). Therefore, in each TR, the γ-ATP resonance can be collected multiple times (e.g. twice in Fig. 1) while the PCr resonance is collected once with only minimal magnetization transfer effects.

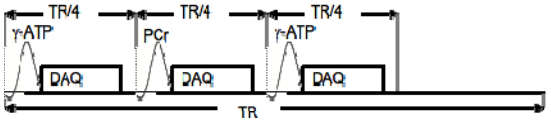
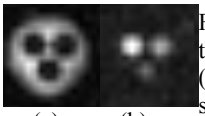


Fig. 1 Illustration of a data acquisition scheme where two resonances (e.g. PCr and γ-ATP) are acquired in each repetition.

Both phantom and *in vivo* human experiments were performed on a 9.4T human scanner with an 80cm bore using a TEM head coil. Consent was obtained for human studies. To demonstrate the spectral selectivity, a sphere phantom filled with 8 mM Na_3PO_4 solution and contains three tubes filled with 3 mM, 6 mM and 9 mM KH_2PO_4 solution was used. The chemical shift between the solution in the sphere and in the tubes was ~3 ppm. phantom and human experiments were performed with the same acquisition parameters. As the frequency shift between PCr and γ-ATP is ~430 Hz at 9.4T, a minimal phase RF pulse of pulse width of 7.2 ms was used to achieve a pulse-band of ~380 Hz width for spectral selection. Other acquisition parameters included a 24 cm FOV and an isotropic image resolution of 1.5 cm. A repetition time of 8 s was used to account for the long T1 of PCr signal, and the effective TE of 2.8 ms was increased by 0.5 ms from the minimal TE available to reduce the baseline signal. The TPI readout duration was ~13 ms and the total data acquisition time was 16.5 minutes.

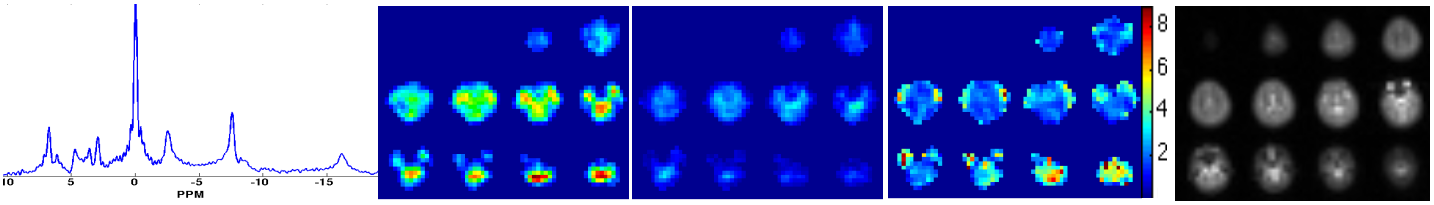
RESULTS AND DISCUSSION

With the current pulse sequence parameters, the average SAR was minimal (< 0.25 W). The phantom images in Fig. 2 show separation of the solutions in the outer sphere and in the internal tubes. The three tubes are well resolved with different signal levels even at a ^{31}P concentration of 3 mM. A whole brain ^{31}P spectrum is shown in Fig. 3a, the resonance peaks of interest are well separated. The PCr (Fig. 3b) and ATP (Fig. 3c) images demonstrate reasonable SNR and spatial resolution. Voxels at the skull base and laterally over the head containing muscle show higher PCr concentration than the central voxels containing brain parenchyma. As shown in Fig. 3d, the PCr/ATP ratio is ~1-2 in brain tissue and is higher (3-9) in voxels containing muscle. This is in general agreement with literature values that this ratio is ~1 in brain tissue and ~8 times in muscle tissue after considering the partial volume effect for the large voxel size. Some image distortion is seen due to B0 inhomogeneity. This can potentially be reduced by careful shimming and by optimizing the TPI readout length.



(a) (b)

Fig.2 Images of the solution in the sphere (a) and in the tubes (b) (3, 6, 9 mM) collected simultaneously show good spectral selectivity and SNR.



(a) (b) (c) (d) (e)

Fig.3 (a) Whole brain spectrum collected in 1.5 minutes with a TR of 3s and 32 averages shows good resolution of the multiple ^{31}P resonances. (b) PCr and (c) γ-ATP images collected simultaneously allow their ratio (d) to be calculated. (e) Low-resolution sodium images used references. Images in (b) and (c) have the same scale. Data acquisition time for ^{31}P imaging was 16.5 minutes with a resolution of 1.5 cm isotropic.

CONCLUSIONS

With the increased sensitivity of 9.4T, ^{31}P images have been obtained with reasonable SNR and spatial resolution in 16.5 minutes. The simultaneous acquisition of PCr and ATP resonances allow their ratio to be calculated, which may potentially enable us to study brain metabolism in an acceptable acquisition time. Future work will further optimize the sequence and validate its applications on humans and develop more SNR efficient coils.

REFERENCE 1. Sappey-Marinier et al. J Cereb Blood Flow Metab 1992; 12:584. 2. Rango et al. J Cereb Blood Flow Metab 2001; 21:85. 3. Chen et al. MRM 1997; 38:551. 4. Lei et al. MRM 2003; 49:199. 5. Greenman R. MRM 2004; 52:1036. 6. Boada et al., Magn Reson Med 1997; 37:706-715.