Comparison of Two Fast MR Acquisition Strategies for Simultaneously Imaging of PCr and γ-ATP in the human brain at 9.4T

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INTRODUCTION: Phosphocreatine (PCr) is a buffer against fluctuations in cytosolic adenosine triphosphate (ATP) concentration that might otherwise occur under changing metabolic workloads. The PCr/γ-ATP concentration ratio therefore provides a measure of the balance of fluxes between the anabolic and catabolic pathways of ATP. However, the low concentrations, long T1 relaxation times and lower MR sensitivity of phosphorus metabolites make quantitative 31P MR imaging studies time-consuming even at low spatial resolution. Fast imaging techniques, such as rapid acquisition with relaxation enhancement (RARE) (1-2) and steady-state free precession imaging (SSFP) (3), and more recently, a novel acquisition strategy now termed SIMPLE-flexTPI for Simultaneously Imaging of Multiple Spectral Peaks with InterLeaved Excitations and Flexible Twisted Projection Imaging Readout Trajectories (4), have been used to acquire spatially resolved 31P signals. The purpose of this work is to investigate the performance of SIMPLE-flexTPI and its RARE equivalent called SIMPLE-RARE on a 9.4 T scanner.

MATERIALS AND METHODS: The two pulse sequences are illustrated in Fig. 1. Both sequences take advantage of the shorter T1 of γ-ATP spins relative to PCr spins (5). For SIMPLE-flexTPI, the PCr resonance was sampled once while the γ-ATP resonance was sampled twice. Immediately following each excitation, the free induction decay (1st echo) signal was sampled with a flexTPI readout trajectory to minimize T2 relaxation. Only the 1st echo data were used in this study. For SIMPLE-RARE, a complete plane in k-space in the slice encoding direction was sampled in a center-out phase encoding order following each excitation for PCr. To account for the shorter T2 value of γ-ATP, γ-ATP imaging used half of the echo train length (ETL) as used for PCr. The same k-space sampled following one excitation for PCr was sampled with two excitations in each TR, also in a center-out phase encoding order.

Human experiments were performed on a 9.4T magnet under an IDE. Informed consent was obtained. The transmit power settings for both the SIMPLE-flexTPI and SIMPLE-RARE sequences were optimized using a phantom with similar electrical loading to an average human head. The SIMPLE-flexTPI and SIMPLE-RARE sequences were performed with the same spectrally selective minimal phase excitation RF pulse (pulse width 7.2 ms, pass-band width 380 Hz), TR (8 s), FOV (24cm) and nominal spatial resolution (1.5cm isotropic). Data acquisition with SIMPLE-flexTPI used a radial fraction of 0.15 and a gradient strength of 0.4G/cm and an ultra-short TE of 510 μs for the 1st echo. TE for the 2nd echo was 9.1 ms. The readout duration for each echo was 7.7 ms. The total acquisition time was 16.5 minutes. The SIMPLE-RARE sequence used a 4 ms refocusing Gaussian RF pulse matching the bandwidth of the excitation RF pulse. The acquisition spectral bandwidth was 4 kHz. The ETL was 16 for PCr and 8 for γ-ATP. The TE was 15.2 ms and the total acquisition time was ~17 minutes.

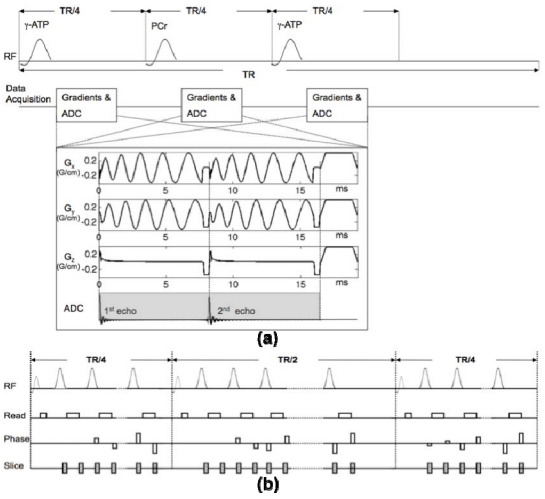

Fig. 1 Illustration of (a) SIMPLE-flexTPI and (b) SIMPLE-RARE sequences for collecting PCr and γ-ATP signal simultaneously.

The same low pass Gaussian filter (standard deviation σ = 0.5) was applied to the k-space data collected with both sequences. For comparison, SNR measurements were made by the ratio of the average signal in regions of interest (ROI) placed over the object and the standard deviation in a background region (6).

RESULTS AND DISCUSSION: The average SAR was minimal for the SIMPLE-flexTPI sequence (< 0.25W) and well below the FDA guideline (3.2W/kg) and that of the SIMPLE-RARE sequence (1.5 W). PCr and γ-ATP images obtained from a volunteer are shown in Fig. 2. The PCr images from the SIMPLE-RARE sequence showed less distortion from B0 field inhomogeneities and slightly better SNR (~10 vs. ~9 for SIMPLE-flexTPI). However, the γ-ATP images obtained with SIMPLE-RARE showed low signal and could not be used for PCr/ATP ratio calculation due to the relatively short T2 of γ-ATP. The γ-ATP images obtained with the SIMPLE-flexTPI sequence showed a much better signal owing to its short TE capability and allowed a meaningful PCr/ATP ratio to be calculated. As shown in Fig. 3, the ratios obtained at improved SNR from two signal averages and a shorter TE of 10 μs are in agreement with literature values (7).

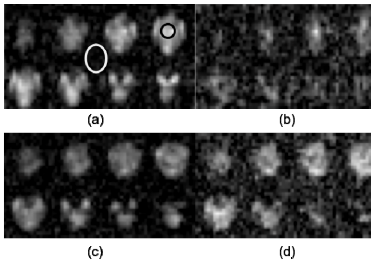

Fig. 2 (a) PCr and (b) γ-ATP images collected with SIMPLE-RARE. (c) PCr and (d) γ-ATP images collected with the SIMPLE-flexTPI. The dark and white circles indicate the ROIs used to for SNR estimation. Acquisition times were 16-17 minutes.

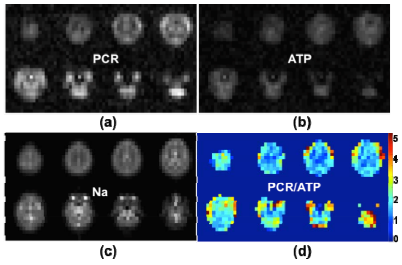

Fig. 3 (a) PCr and (b) γ-ATP images collected with the SIMPLE-flexTPI sequence in 33 minutes with two signal averages. (c) co-registered ^{23}Na reference images. (d) PCr /γ-ATP ratio maps.

Although not an issue with the parameters used in this study, the peak SAR constraint does limit the echo train length and the choice of refocusing RF pulse for the SIMPLE-RARE sequence in other experiments. T2 relaxation in SIMPLE-flexTPI results in continuous signal loss and well-understood image blurring. T2-related signal loss in SIMPLE-RARE is segmented and may introduce additional signal intensity modulation, especially when the T2 is relatively short. SSFP has also been suggested as an efficient fast imaging approach for ^{31}P imaging. It was not considered in this work as its signal is a complex functions of parameters such as T1, T2, flip angle and is very sensitive to B0 field inhomogeneity, complicating the interpretation of signal intensities. Furthermore, SSFP often uses short TR values along with large flip angles, making SAR a major concern at 9.4T.

CONCLUSIONS: Our results show that both the SIMPLE-flexTPI and SIMPLE-RARE sequences achieved comparable SNR efficiency for PCr imaging. However, the SIMPLE-flexTPI sequence performed better for γ-ATP imaging due to its short TE capability, and therefore is more suitable for mapping the PCr/ATP ratio.

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