^{31}P MRS in Human Brain at 4T and 7T: Signal-to-Noise Ratio and Spectral Resolution Comparisons

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INTRODUCTION

It has been demonstrated that ^{31}P MRS quality acquired in the human brain is significantly improved at 7T [1]. In this work, we focused on quantitative comparisons of ^{31}P sensitivity and spectral resolution between 4T and 7T. For a given nucleus, SNR is determined by longitudinal relaxation time (T_1), apparent T_2 (T_2^*), RF coil Q factor and magnetic field strength (B_0) according to the relationship given by Equation (1) [2]. Since $T_2^* = 1/(\pi \Delta \gamma_{1/2})$, where $\Delta \gamma_{1/2}$ is linewidth, we can rewrite Equation (1) into Equation (2). Motivated by this relationship, we measured the T_1 and $\Delta \gamma_{1/2}$ values, Q factors and SNRs of the PCr resonance peak in the ^{31}P MRS of human visual cortex at both 4T and 7T using the same methodology under the same experimental conditions.

$$SNR \propto B_0^\beta \sqrt{Q \cdot T_2^* / T_1} \quad (1) \qquad SNR \propto B_0^\beta \sqrt{Q / (\Delta \gamma_{1/2} \cdot T_1)} \quad (2)$$

METHODS

All experiments were performed on a Varian (Palo Alto, CA) console interfaced either to a 4 Tesla or to a 7 Tesla whole body MR scanner. Identical passively decoupled dual-coil configurations were designed and constructed for both field strengths, with a linear butterfly proton surface coil for anatomical imaging and shimming, and a 5-cm diameter single-loop surface coil, designed for covering the human primary visual cortex only, for ^{31}P spectroscopy. The noise figure of preamplifier and NMR receiver was identical at 4T and 7T. T_1 was measured with a fully relaxed inversion-recovery sequence (TR= 16 s), a hard excitation pulse of 200 µs for achieving a maximal signal intensity of PCr, a spectral width of 5000 Hz and a total of eight inversion times (TIs) ranging from 8 ms to 20 s. No additional spatial localization was used, except that achieved by the surface coil itself. A simulation program developed by Varian (CA) was utilized to fit and calculate T_1 values. Eight normal subjects were recruited for this study, three of them for SNR comparison and the other five for T_1 measurements at 4 T.

RESULTS

Figure 1a shows a sagittal image of the primary visual cortex on which the position of the ^{31}P coil is indicated. Figure 1b and 1c illustrate a spectrum from the same subject acquired with TR of 3 s and 128 averages at 4T and 7T, respectively. The PCr T_1 relaxation times, linewidths ($\Delta \gamma_{1/2}$), RF coil Q factors and SNRs at 4T and 7T are summarized in Table 1. Inserting all these parameters into Equation (2), we get $\beta = 2.0$.

DISCUSSION and CONCLUSION

The T_1 relaxation time of PCr in human brain does not change significantly between 1.5T to 7T (Figure 2, P>>0.05), presumably because there are two competing relaxation mechanisms that simultaneously influence the ^{31}P relaxation times: chemical shift anisotropy and dipolar interaction [3]. The former one will decrease T_1 with increasing B_0, while the later one will increase T_1. The opposite trends between these two relaxation mechanisms could lead to an approximately field independence of PCr T_1. Based on our analysis using Equation (2), which accounts for all contributions to SNR as a function of B_0, we found $\beta = 2.0$, which was consistent with the theoretical prediction of 7/4. The linewidth broadening of PCr peak with increased field strength was less than linear relationship. This reveals an improved spectral resolution at 7T. Most importantly, the apparent sensitivity was doubled at 7T compared to 4T. All these results indicate the great advantages at high field for improving ^{31}P MRS quality in both sensitivity and spectral resolution. Such improvements make in vivo ^{31}P MRS capable to determine the ATP synthesis rate in the human visual cortex non-invasively [4].

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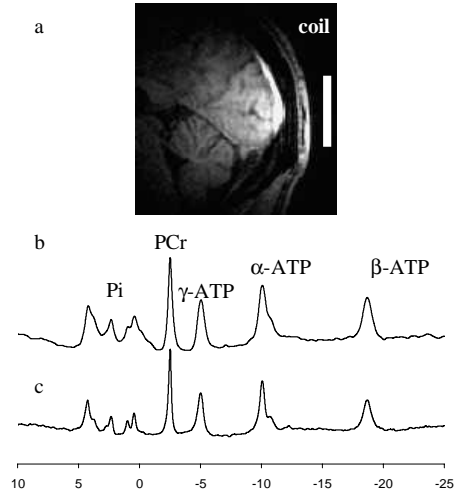[4]. H. Lei, et al. *PNAS USA* 100; 14409-14414 (2003).

FIG. 1. Anatomical image and ^{31}P spectra acquired from human primary visual cortex at 4T (b) and 7T (c), respectively.
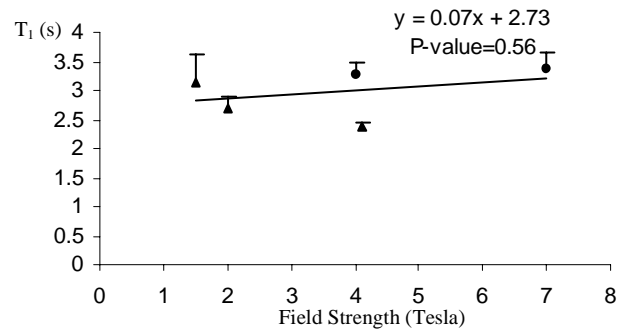

FIG. 2. Field dependence of PCr T_1 in human brain from the literature data [1] and our measurements.

	T_1 (s)	$\Delta \gamma_{1/2}$ (Hz)	Q	SNR
7 T	3.37±0.29[1]	13.3±0.5	79.5	108.2±11.6
4 T	3.27±0.23	9.2±0.5	130	53.8±4.8
ratio	1.03	1.45	0.61	2.01

Table. 1 Relaxation times and linewidths of PCr, RF coil Q factors and SNRs at 4T and 7T.