# Quantitative Comparison of $^{31}$P Relaxation Time and NMR Sensitivity between 9.4T and 16.4T

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**Introduction** *In vivo* $^{31}$P MRS allows direct measurement and quantification of high energy phosphates such as adenosine triphosphate (ATP) and phosphocreatine (PCr), as well as the inorganic phosphate (Pi) level and intracellular pH. Using magnetization transfer techniques, it is also possible to measure the rate of ATP synthesis and the flux through creatine kinase system. Thus, $^{31}$P MRS provides a unique tool to directly investigate the mechanisms of synthesis, transfer and utilization of the high energy phosphate compounds, which has significantly advanced our understanding of bioenergetics in tissues. However, the efforts of *in vivo* $^{31}$P MRS have been suffered from the low NMR detectable concentrations of phosphate compounds, low NMR sensitivity due to its relatively low gyromagnetic ratio, limited spectral and spatial resolution. It is known that the optimal signal-to-noise ratio (SNR) depends on field strength ($B_0$), $T_1$, linewidth ($\Delta\nu_{1/2}$), repetition time (TR), the RF coil quality factor (Q) and other factors according to the following relationship (1):

$$B_0^{\beta} Q^{1/2} \left(\frac{1}{T_1 \cdot \Delta\nu_{1/2}}\right)^{1/2} (1 - E_2^2)^{1/2} G(\mathrm{TR}/T_1)$$

One way to improve the NMR sensitivity and spectral quality is to increase $B_0$. Previous study has compared the *in vivo* $^{31}$P NMR sensitivity of human brain between 4T and 7T (1), suggesting advantages of high field. In this study, $^{31}$P NMR sensitivity and relaxation time were measured from phantom solution and rat brain at 9.4 and 16.4 Tesla to quantify the possible SNR gain for *in vivo* $^{31}$P MRS application using the newly developed large-bore animal scanner with ultrahigh field of 16.4T.

**Methods** All measurements were performed on either a 9.4T/31cm or a 16.4T/26cm bore magnet (Magnex Scientific) interfaced to VNMRJ consoles (Varian, CA). For *in vitro* studies, a $^{31}$P radiofrequency (RF) probe consisting of a one-turn, oval (18mm×13mm) shaped surface-coil was designed and constructed. Its resonance frequency can be tuned to either 162 MHz for 9.4T or 283 MHz for 16.4T application. A 6mm-diameter glass sphere filled with high concentration Pi was fixed on the RF probe for all phantom studies at both fields. For *in vivo* studies, two passively decoupled dual-coil RF probes with identical geometry were constructed and placed over the cortical regions in the rat brain to obtain optimum *in vivo* sensitivity for both 9.4T and 16.4T experiments. Each RF probe included a one-turn, oval (14mm×20mm) shaped single loop $^{31}$P surface-coil and a linear butterfly $^{1}$H surface-coil (28mm×20mm) for shimming and anatomical images. Male Sprague Dawley rats were anesthetized and imaged for (i) global SNR quantification at 9.4T and 16.4T; and (ii) $T_1$ measurements of PCr and 3D $^{31}$P MRS imaging acquisition for localized spectral SNR comparison. A single-pulse-acquire sequence was applied to obtain the optimal $^{31}$P SNR with a nominal 90º RF excitation pulse and following acquisition parameters: 20 kHz spectral width (SW), 1024 number of points (NP) for each FID, 16 s repetition time (TR) with 4 or 16 averages (phantom); SW=8 kHz, NP=1024, TR=10 s with 8 averages (rat brain). $T_1$ was measured at fully relaxed condition with TR=16 s using inversion recovery for both field strengths. The spatial localization of $^{31}$P MRS was achieved by using 3D Fourier series window MRS imaging technique with 1.5 s TR, 512 NP, 8 kHz SW, 4 repetitions, 7×7×5 matrix and 30mm×30mm×30mm FOV. The raw NMR signal was processed by exponential filtering with a line broadening of 20 Hz to enhance SNR, followed by Fourier transformation. The $^{31}$P NMR sensitivity was evaluated using the SNR of PCr resonance peak calculated by dividing peak intensity by the peak-to-peak spectral noise and multiplying it by 2.5.

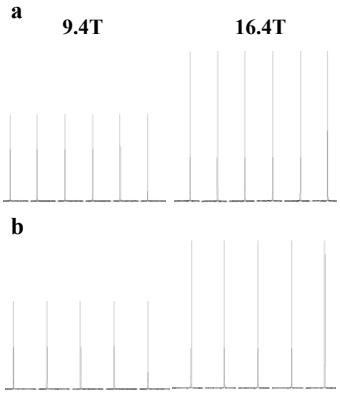


**Figure 1.** $^{31}$P spectra of the sphere with 4 (**a**) and 16 (**b**) averages.

**Results** Figure 1 shows the $^{31}$P NMR spectra from the sphere phantom at two field strengths with the same vertical display scale. Figure 2 illustrates the exponential fittings of the PCr signals as a function of the inversion time for rat brain $T_1$ measurement. The measured *in vivo* $T_1$ values of PCr were 3 s and 1.5 s at 9.4T and 16.4T, respectively. The 2D axial $^{31}$P spectra obtained from *in vivo* 3D MRS images were shown in Figure 3. As summarized in Table 1, the average $^{31}$P SNR gain at 16.4T was ~1.6-fold higher than that at 9.4T for both of the phantom and rat brain studies. The overall results clearly demonstrate excellent sensitivity at both fields for obtaining the $^{31}$P signals from either phantom or brain. Nevertheless, the 16.4T scanner offers striking improvements in the $^{31}$P NMR sensitivity and spectral resolution as well.

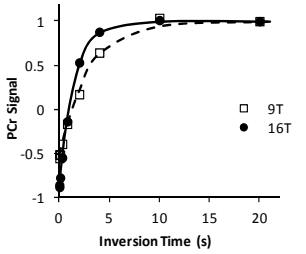


**Figure 2.** $^{31}$P $T_1$ measurement of PCr from rat brain.

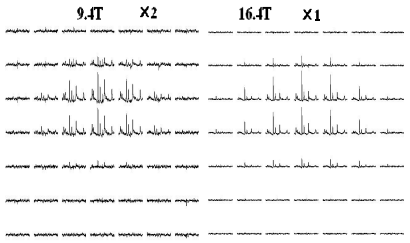


**Figure 3.** Axial 2D spectra obtained from the central slides of 3D $^{31}$P-MRS images in rat brain at 9.4T (left) and 16.4T (right).

**Table 1.** $^{31}$P SNR comparisons between 9.4T and 16.4T

| | Sphere (4 averages) | Sphere (16 averages) | Rat Brain (8 averages) | Rat Brain (Central Vox.) |
|---|---|---|---|---|
| $SNR_{9.4T}$ | 360.8±12.5 | 697.6±38.5 | 52.1±3.2 | 61.0±2.2 |
| $SNR_{16.4T}$ | 518.7±18.1 | 1093.2±83.3 | 84.5±1.5 | 102.8±5.9 |
| $SNR_{16.4T}/SNR_{9.4T}$ | 1.44 | 1.57 | 1.62 | 1.69 |

**Discussion and Conclusion** In the present study, we examined the $^{31}$P relaxation time and NMR sensitivity at two high field strengths. The results indicate an approximated 1.6-fold SNR gain and half $T_1$ value at 16.4T compared with 9.4T. Also, an approximated 1.4 power (β=1.4) dependence of $^{31}$P SNR on $B_0$ was indicated after considering all the factors according to the above relationship, and this value is consistent with previous report (1). In summary, our preliminary findings clearly indicate that the increasing field strength could significantly improve the *in vivo* $^{31}$P MRS quality and spatial resolution, and shortening the total acquisition time for localized $^{31}$P MRS or imaging. It benefits the application of $^{31}$P MRS in detecting altered bioenergetics associated with brain function and neurological diseases.

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**References** 1. Qiao, H. Y., Zhang, X. L., Zhu, X. H., Du, F., and Chen, W. (2006) *Mag. Reson. Img.* **24,** 1281-1286.