In vitro and *In vivo* Studies of ^{17}O NMR Sensitivity at 9.4 and 16.4 Tesla

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Introduction

The lack of non-destructive and robust *in vivo* imaging approaches for investigating cellular oxidative metabolism has limited our understanding of the mechanism underlying metabolic alteration between normal and diseased tissues. Direct observing the dynamics of metabolic $H_2{}^{17}O$ production from the reduction of ^{17}O-labled oxygen gas provides an opportunity to quantify and image the cerebral rate of oxygen consumption ($CMRO_2$) *in vivo*. However, the efforts of direct monitoring the accumulation rate of $H_2{}^{17}O$ have been suffered from the low NMR detection sensitivity due to the very low gyromagnetic ratio of the ^{17}O spin and low $H_2{}^{17}O$ content. It is known that the optimal signal-to-noise ratio (SNR) for detecting NMR signals depends on field strength (B_0), T_1, T_2* and the RF coil quality factor (Q) according to the following relationship:

$$SNR \propto B_0^{\beta}\sqrt{\frac{QT_2^*}{T_1}}$$

Two previous studies have compared the *in vitro* and *in vivo* ^{17}O NMR sensitivity between 4.7T and 9.4T, and between 4.7T and 11T, respectively (1,2), suggesting great advantages of high field. The unique properties of ^{17}O, i.e., the independence of ^{17}O relaxation times (T_1 and T_2) on the field strength (1,2) and extremely short T_1, also contribute to a large gain of ^{17}O NMR sensitivity at high/ultrahigh field. In this study, ^{17}O NMR sensitivity was measured and compared using the natural abundance $H_2{}^{17}O$ signal in phantom solution and rat brain at 9.4T and 16.4T to quantify the possible SNR gain for *in vivo* ^{17}O NMR application using the newly developed large-bore animal scanner with ultrahigh (highest) field of 16.4T.

Methods

All NMR 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 both *in vitro* and *in vivo* studies, a ^{17}O radiofrequency (RF) probe consisting of a two-turn, oval (18mm×13mm) shaped surface-coil was designed and constructed. Its resonance frequency can be tuned to either 54.25 MHz for 9.4T or 94.65 MHz for 16.4T application. A 6mm-diameter glass sphere filled with natural abundance ^{17}O water was fixed on the RF probe for all phantom studies at both fields. A male Sprague Dawley rat was anesthetized and imaged for measuring and quantifying SNR of natural abundance brain $H_2{}^{17}O$ at 9.4T and 16.4T using the same surface-coil, which was placed over the cortical regions in the rat brain to obtain optimum *in vivo* sensitivity. The single-pulse-acquire sequence was applied to obtain the optimal ^{17}O SNR with a nominal 90º RF excitation pulse and following acquisition parameters: 20 kHz spectral width, 512 number of points for each FID, 7 s temporal resolution with 128 signal averages for phantom measurements and 512 (28 s temporal resolution) or 128 averages for *in vivo* studies. The raw NMR signal was processed by exponential filtering with a line broadening of 100 Hz to enhance SNR, followed by Fourier transformation. The ^{17}O NMR sensitivity was evaluated using the SNR of $H_2{}^{17}O$ resonance peak calculated by dividing peak intensity by the standard deviation of the noise. Another relevant question is whether the ^{17}O signal is stable among repeated measurements; thus, the stability of the ^{17}O signal was also assessed by computing the standard deviation of $H_2{}^{17}O$ signals from 10 repetitions of data acquisition.

Results

Figure 1 shows typical ^{17}O NMR spectra of natural abundance $H_2{}^{17}O$ acquired from the sphere phantom and *in vivo* rat brain at two field strengths with the same vertical display scale. The average ^{17}O SNR gain at 16.4T was 2.9 and 2.6-fold higher than that at 9.4T, for the phantom and rat brain studies, respectively, as summarized in Table 1. The ^{17}O signal stabilities at both field strengths are also shown in Table 1. The overall results clearly demonstrate excellent sensitivity and high stability at both fields for obtaining the ^{17}O signals of natural abundance $H_2{}^{17}O$ (lowest concentration in nature) from either phantom or brain. Nevertheless, the 16.4T scanner offers striking improvements in both sensitivity and reproducibility.

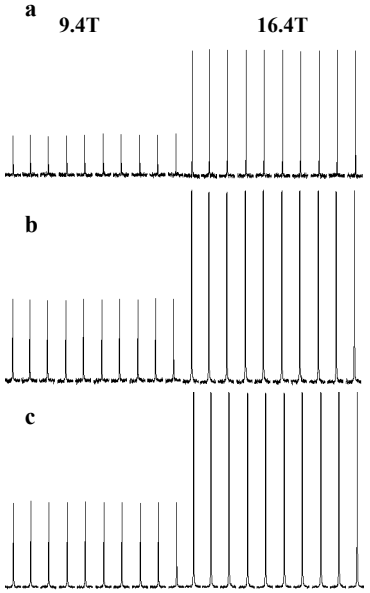

Figure 1. ^{17}O spectra of the sphere (**a**) and *in vivo* rat brain (**b**) with 128 averages. *In vivo* rat brain ^{17}O spectra with 512 averages (**c**).

Discussion and Conclusion

In the present study, we examined the *in vitro* and *in vivo* ^{17}O NMR sensitivity at two high field strengths. The results indicate an approximated 2.6~3-fold SNR gain at 16.4T compared with 9.4T. Also, an approximated square power (β=1.7~2) dependence of ^{17}O SNR on B_0 was indicated, and this value is consistent with previous reports (1,2) and the theoretical prediction of 7/4. The significant SNR improvements achieved at 16.4T should benefit 3D $CMRO_2$ imaging based on the ^{17}O MRS method, which should provide an opportunity to detect altered oxidative metabolism associated with brain function and neurological diseases with improved spatial and temporal resolutions.

Table 1. ^{17}O SNR and signal stability comparisons between 9.4T and 16.4T

	Sphere (128 averages)	Rat Brain (128 averages)	Rat Brain (512 averages)
$SNR_{9.4T}$	36.8± 3.5	69.9± 5.8	142.4± 15.8
$SNR_{16.4T}$	108.4± 11.3	178.6± 8.1	349.6± 46.8
$SNR_{16.4T}/SNR_{9.4T}$	2.9	2.6	2.5
Stability at 9.4T	2.19%	0.84%	0.66%
Stability at 16.4T	0.53%	0.43%	0.27%

Acknowledgements

This work is supported in part by NIH grants NS41262, NS57560, P41 RR08079 and P30 NS057091, S10 RR025031; and the Keck foundation.

References

1. Zhu, X. H., Merkle, H., Kwag, J. H., Ugurbil, K., and Chen, W. (2001) *Mag. Reson. Med.* **45,** 543-549.
2. Thelwall, P. E., Blackband, S. J., Chen, W. (2003) *Proc. Intl. Soc. Mag. Reson. Med*. p. 504.