In Vivo Localized Spectroscopy using Ultra-Slow Magic Angle Spinning

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Introduction

Susceptibility gradients arising near the boundaries of intra- and inter-cellular compartments broaden the MR metabolite lines, and especially for *in vivo* ^{1}H MRS in areas outside the brain the susceptibility broadening becomes so large that it seriously hampers spectral analyses. Recently it was shown that by combining special R.F. pulse sequences and slow magic angle spinning (MAS) of the sample this broadening can be eliminated. For one of these methods, phase corrected magic angle turning (PHORMAT), spinning speeds as low as a few Hz can be used. This makes PHORMAT amenable for *in vivo* applications, as was demonstrated in a live mouse (1). However, so far slow-MAS spectroscopy was not spatially selective, and in this presentation the first results will be shown of volume-selective slow-MAS MRS.

Methods

Figure 1 shows the used RF and gradient pulse sequence of this so-called LOCMAT (localized magic angle turning) experiment. The used RF sequence is similar to the one originally proposed by Bax et al. (2). It utilizes three $\pi/2$ excitation pulses r_1-r_3, applied at one third of the rotor period T_r, and two $\pi/2$ projection pulses p_1 and p_2, applied at a time $t_1/3$ after r_1 and r_2. It can be shown that at the time $t_1/3$ after r_3 the signal decay during t_1 due to the susceptibility gradients is eliminated, so by acquiring the signal during t_2 for variable evolution times t_1 a 2D spectrum is obtained from which the isotropic spectrum can be obtained (2). Compared with PHORMAT this RF sequence has the advantage that it requires half the measuring time, but the disadvantage is that the spectra have to be displayed in absolute-value mode, thus reducing its spectral resolution. Volume selectivity is obtained in a way similar to STEAM by making three RF pulses frequency selective and combining them with pulsed field gradients. However, in LOCMAT it suffices to use a single laboratory frame gradient, $(G_z)_L$, rather than three orthogonal gradients. The reason is that magic angle spinning takes place around the [1,1,1] axis, so at times 0, $T_r/3$, and $2T_r/3$ this gradient produces three orthogonal gradients $(G_i)_R$, i=x, y, z, in a frame rotating synchronously with the object (3). Finally, during the two lock periods L CHESS and WET water-suppression (W.S,) sequences are applied. The LOCMAT experiments were carried out on a Varian UnityPlus spectrometer equipped with a 2T horizontal-bore small animal MRI magnet and a home-built mouse-MAS probe (1).

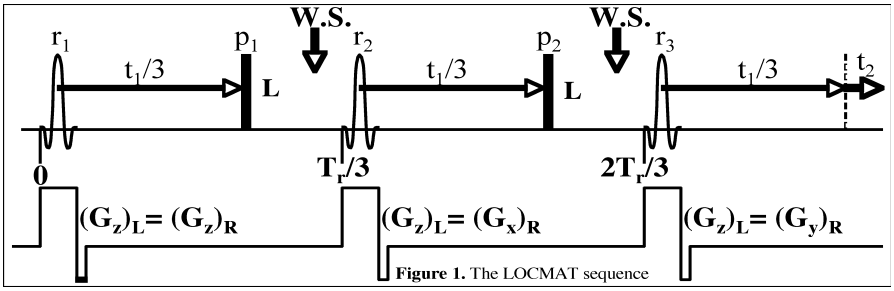

Figure 1. The LOCMAT sequence

Results and Discussion

Figure 2a shows an image obtained on a stationary anaesthetized female BALBc mouse and the 12x12x12 mm^3 voxel selected in the liver area for spectroscopy. The coordinates of the voxel center are used to calculate its position at the times 0, $T_r/3$, and $2T_r/3$ during the spinning and the off-set frequencies of the selective R.F. pulses necessary to select the same voxel in the rotating frame. Figure 2b shows the ^{1}H metabolite spectra obtained in this voxel with standard STEAM on a stationary animal, and Fig. 2c shows the isotropic

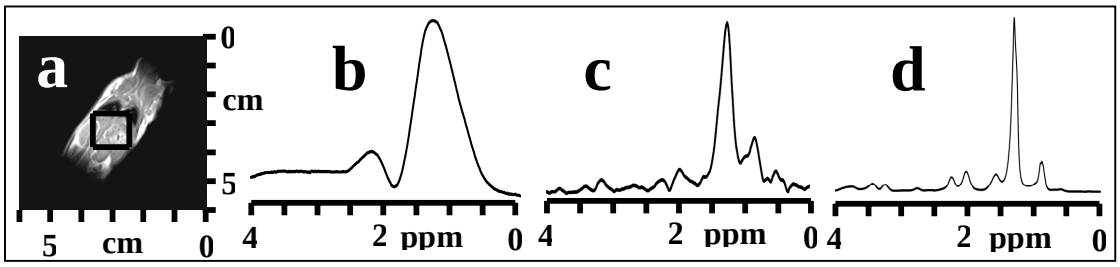

***Figure 2**. a): 86 MHz image of a stationary mouse placed in a rotor at the magic angle; b): 86 MHz ^{1}H water-suppressed STEAM metabolite spectrum of the 12x12x12 mm^3 voxel indicated in (a), obtained in a stationary mouse (TE=13 msec; TM=133 msec; TR=1.2 sec; NEX=32); c) 86 MHz ^{1}H isotropic water-suppressed LOCMAT spectrum of the same voxel (MAS speed=2.5 Hz; number of evolution steps = 68, each with 32 phase steps; evolution increment=1.67 msec; TR=1.2 sec); d): 300 MHz ^{1}H water-suppressed PASS spectrum of freshly excised mouse liver (MAS speed=100 Hz; number of evolution steps=16, each with 32 phase steps; TR=2 sec).*

LOCMAT spectrum obtained while subjecting the animal to 2.5 Hz MAS. A significant increase in spectral resolution is obtained, despite the fact that spectrum 2c is in absolute-value-mode. Figure 2d shows a spectrum obtained on a freshly excised mouse liver in a 7T magnet with another slow-MAS method called PASS (phase adjusted spinning sidebands) (4). It follows that the metabolic profiles in both spectra are very similar, that the presence of metabolites such as choline (3.25 ppm), that are virtually invisible in the STEAM spectrum, are clearly observed with LOCMAT. In fact, even though the PASS spectrum is a pure-absorption mode spectrum, it can be concluded that the spectral resolution of the *in vivo* LOCMAT spectrum would have been at least the same as that of the *in vitro* PASS spectrum if both spectra were measured in a same external field.

Conclusion

We conclude that ^{1}H LOCMAT makes it possible to obtain high-resolution metabolite spectra in heterogeneous areas of the body containing strong macroscopic and microscopic susceptibility gradients that can not or only partially be eliminated with localized shimming. Still, LOCMAT has still significant problems such as a long measuring time, a reduced sensitivity, which is mainly caused by increased noise arising from the presence of spurious signals in the 2D spectra due to unwanted coherences, and the use of absolute-value-mode spectra. At the presentation methods will be discussed to improve this situation. If these improvements are successful, LOCMAT might become a powerful tool for biomedical studies in live animals.

Acknowledgments

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References

1. Wind RA et al. Magn. Res. Med. 50, 1113 (2003).
2. Bax A et al., J. Magn. Res. 52, 147 (1983).
3. Ackerman JL, US patent 4,654,593 (1987).
4. Hu JZ et al. Magn. Res. Med. 46, 213 (2001).