^{13}C spectroscopic imaging of glycogen and metabolites in the rat brain

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Introduction

The localization of the resonances of glycogen, which cannot be detected with regular ^{1}H spectroscopic imaging due to its short relaxation times, remains restricted to localization on the ^{13}C polarization. The resonance of glycogen C1 at 100.5 ppm renders the simultaneous measurement of metabolites other than glucose difficult due to the large chemical shift displacement error. The Fourier series-window (FSW) is an alternative approach to spatial localization that is normally implemented with the Fourier transform. Its main advantages are an arbitrary voxel shape, low cross-voxel contamination and the complete lack of chemical shift displacement (1).

The goal of this study was twofold: first, to determine the feasibility and performance of the application of the FSW to ^{13}C spectra with high spectral width *in vivo*; second, to map the distribution of several ^{13}C labeled metabolites.

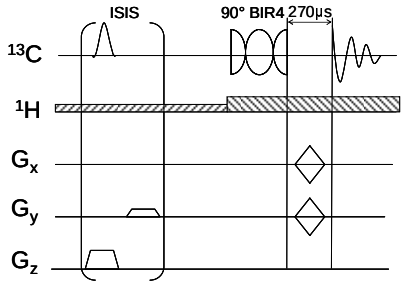

Figure 1: *The FSW pulse sequence including ISIS and decoupling*

Materials and Methods

Male Sprague-Dawley rats (n=2, w = ~250 g) were anesthetized using 1.5% isoflurane and a femoral vein was catheterized for infusion. After surgery isoflurane was switched off and α-chloralose (26.7 mg/kg/hr) was infused. Blood pressure, respiration rate and temperature were maintained within normal range. A quadrature ^{1}H coil with a single 3-loop ^{13}C coil was used. The animal was then inserted into a Varian Inova 9.4T 31 cm bore actively-shielded magnet (400mT/m in 120us).

A 3 ms BIR4 90° pulse was used for excitation and a short time of 270 µs was used for phase encoding (Fig. 1). Waltz-16 NOE and decoupling were applied at the glycogen/glucose ^{1}H frequency, and ISIS was used for slice selection. The FSW was set to a FOV of 22x22 mm with 10 mm slice thickness. 8 coefficients were used in each direction, resulting in 289 gradient variations and a total of 7062 acquisitions. With TR = 1 s, total acquisition time was 1h58m. The study took place after an 8 hour C1,6-13C glucose infusion, and the carrier was placed between the resonances of C1 and C6 glycogen (100.5 and 61.4 ppm respectively). The dataset was processed in MATLAB, and the window was moved with steps of 1/32nd of the FOV to obtain a metabolic map of 32x32. The dataset was processed in MATLAB, and the window was moved with steps of 1/32nd of the FOV to obtain a metabolic map of 32x32 pixels. Spectra were processed with a 0.045 s Gaussian curve and 20 Hz line broadening.

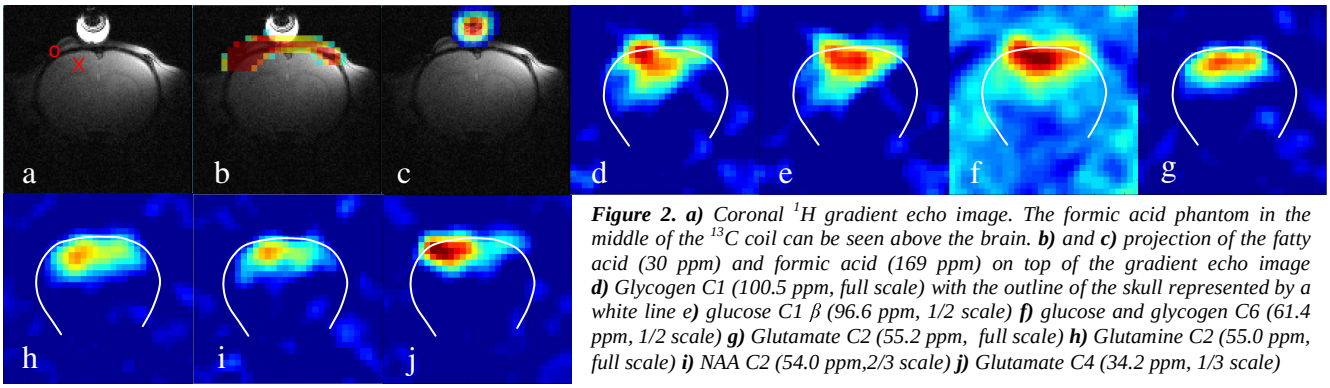

Figure 2. a) *Coronal ^{1}H gradient echo image. The formic acid phantom in the middle of the ^{13}C coil can be seen above the brain.* ***b)*** *and* ***c)*** *projection of the fatty acid (30 ppm) and formic acid (169 ppm) on top of the gradient echo image* ***d)*** *Glycogen C1 (100.5 ppm, full scale) with the outline of the skull represented by a white line e) glucose C1 β (96.6 ppm, 1/2 scale)* ***f)*** *glucose and glycogen C6 (61.4 ppm, 1/2 scale)* ***g)*** *Glutamate C2 (55.2 ppm, full scale)* ***h)*** *Glutamine C2 (55.0 ppm, full scale)* ***i)*** *NAA C2 (54.0 ppm,2/3 scale)* ***j)*** *Glutamate C4 (34.2 ppm, 1/3 scale)*

Results and Discussion

The lipid signal at 30.5 ppm localized to the extracerebral fat on the anatomical image (Fig. 2b) and the reference formic acid signal at 169 ppm to the reference sphere at the RF coil center (Fig. 2c) showing accurate localization of the signals by the FSW technique. The depth sensitivity profiles of all metabolite maps reflect the sensitive volume of the small ^{13}C surface coil (Fig. 2d-j). The glutamine, NAA and glutamate signals (fig. g-j) are clearly localized to the brain. Glycogen on the other hand contains both cerebral and extracerebral localization (Fig. 2d, f). Spectra of the cortex (Fig. 3a, b) are characteristic for brain and those in muscle show signal from the glycerol moiety (fig. 3b).

We conclude that the application of FSW to ^{13}C spectroscopic imaging of broad spectra is feasible, and that brain glycogen can be mapped with a nominal 76 µl voxel volume *in vivo*.

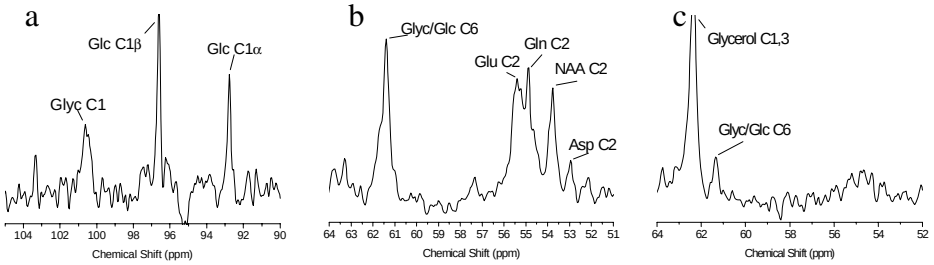

Figure 3. a) *Spectrum of glucose C1 region of a 76 µl voxel in the cortex (red cross in Fig. 2a).* ***b)*** *In the same spatial region the glycerol signal appear to be almost completely filtered out, while metabolites are well resolved (twice the scale of 3a).* ***c)*** *The same spectral region in the subcutaneous fat (circle in Fig. 2a). Glycerol is visible together with a small amount of glycogen and glucose, while the metabolites are almost completely filtered out.*

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References

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