Imaging of physiologic lactate concentrations by SelMQC spectroscopy with Hadamard slice selection on a clinical scanner

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Objective

Our objective is to implement selective homonuclear multiple-quantum coherence-transfer (Sel-MQC) lactate spectroscopy with three-dimensional localization on a clinical scanner. Slice selection was performed by Hadamard encoding in the one dimension with two dimensions of phase encoding.

Background

Many approaches have been proposed for the imaging of lactate *in vivo*, however the Sel-MQC technique (1) offers several advantages over other sequences. Complete fat and water suppression can be obtained with a single zero quantum scan. Also, this same technique with double quantum selection gradients and two phase-cycled averages results in full lactate signal and full fat and water suppression. The original technique provides for 2-dimensional phase encoding (PE), however 3-dimensional encoding has been desired for *in vivo* applications such as mapping the distribution of lactate across tumors. Early implementations using 2 slice or 4 slice PE were unsuccessful due to the poor point spread function of PE across so few dimensions. Further, a signal to noise efficiency penalty made such scanning unacceptable for clinical detection of lactate *in vivo*. By contrast, Hadamard style slice selection (2) acts as an additional average for each repetition and even 2 slices may be well localized with this technique. While 2D (3,4) versions and very recently a 3D (5) version of this technique have been used for small animals, rarely is lactate editing realized on clinical scanners. Here we demonstrate 3D Sel-MQC lactate imaging with clinical hardware with the goal of future studies on human tumors and ischemic diseases such as stroke.

Methods

Frequency modulated adiabatic hyperbolic secant pulses were generated in Matlab according to : $\mathrm{sech}(\beta t)^{1+i\mu}\sum e^{ift}$ where β is 1.978, t goes from $-\pi$ to $+\pi$, i is sqrt(-1), μ determines the width of the inversion (20 for pulse 1, 10 for pulses 2,3,7, and 5 for pulses 4,6,8 in Fig. 1) and each frequency f determines the frequency offset (pulses 3,7) or offsets (pulses 4,6,8). These were simulated by Fourier and Hadamard Transformations as shown in Figures 1 and 2 and then exported to the Siemens Pulsetool. To the standard gradient recalled echo sequence was added a user-selectable pre-encoding Hadamard pulse applied in the readout direction of the FoV followed by a spoiler. The phase map output was used to calibrate the required power and gradient amplitudes for the Hadamard encoding pulses as shown in Figure 3. All images were taken with a standard Bruker T/R human head coil connected to a 3T Siemens Trio clinical scanner. The parameters for the GRE calibration sequence performed on a 10cm diameter saline phantom were: TR 500ms, TE 3.67ms, FoV 100x100, Matrix 64x64, BW 260Hz/Px, α=30°. Lactate imaging was performed on 15mL conical tubes filled with 100% safflower seed oil or varying concentrations of lactate in water with .01% sodium azide to prevent spoiling. These tubes were submerged in water in a 10cm diameter sealed jar for imaging. The final pulse sequence is diagrammed in (Ref. 1, Fig. 1a) except for the addition here of 2D PE gradients after the final quantum selection gradient and the addition of CHESS water suppression and the hyperbolic secant pulse and a spoiler before the sequence. Outer Volume Suppression is also available. For chemical shift imaging for both DQ and ZQ protocols the parameters were: TR 1.5s, FoV 10x10cm, Matrix 10x10, 4 Slices (8 Hadamard Pulses) 10mm each, 4000Hz BW, 2048 points, 2 phase cycled averages, quantum selection gradients 26mT/m, 300μs duration, 300μs ramp time, Gaussian pulses 7800ms duration (~1ppm width) centered on the CH or CH_3 frequency. A total scan time of almost 20 minutes was achieved by elliptical k-space sampling in each 2D plane. Raw data was processed by custom written software in IDL. After transformations, the magnitude spectrum area under the lactate peaks for each voxel was integrated and then the image was interpolated to the viewed resolution.

Results

Figure 1 shows simulated slice profiles for the Hadamard slice selection. Each number indicates the pulse number and the combination of + and – indicates a full inversion (-) or non-inversion (+) performed by that pulse. Application of the Hadamard transform matrix to these slice profiles results in the simulated slice profile in Figure 2. A demonstration on the clinical scanner of the Hadamard pulses is shown in Figure 3, the numbers represent the Hadamard pulse # as shown in Figure 1. The arrangement of the phantoms and numbers labeling the concentration of lactate in each phantom (mM), is shown in Fig. 4a and the 4 slice selection region is shown as the yellow box in Fig 4b. Figures 5 and 7 show the 4 slices of DQZQ and DQDQ respectively and Figures 6 and 8 show an overlay of the topmost slices on the phantom image. Note that 10mM is easily observable in both cases and even 5mM is seen in both acquisitions. Fat suppression here is shown to be 1000x in the DQ-ZQ case and appears to be complete in the DQ-DQ case, assuming that there is no patient motion. Water suppression is nearly complete.

Figure 1

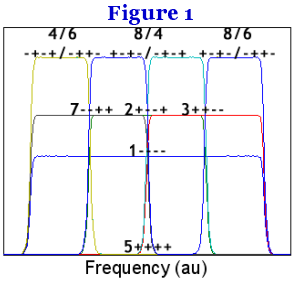


Figure 2

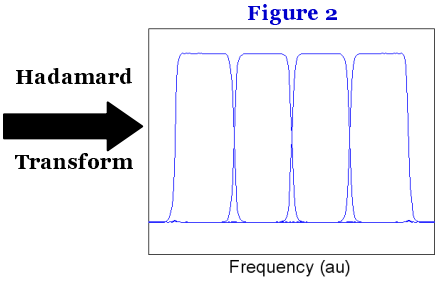


Figure 3

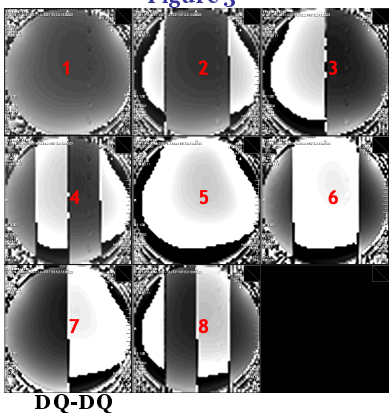
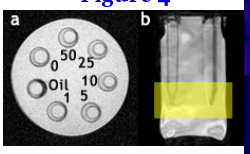
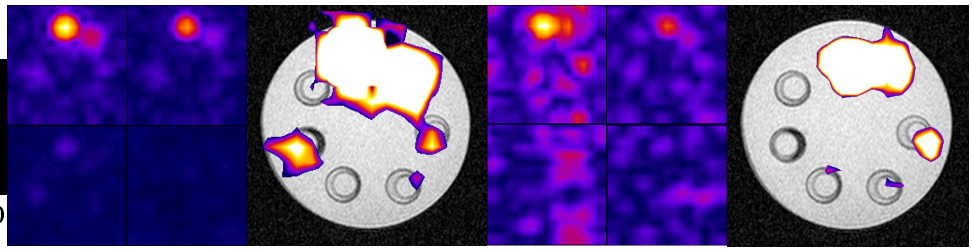


Figure 4



(numbers are mM lactate)

Figure 5 DQ-ZQ **Figure 6** **Figure 7** DQ-DQ



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