Short Echo Spectroscopic Imaging combined with Lactate Editing in a single scan

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Introduction: Magnetic resonance spectroscopic imaging (MRSI) is a powerful tool for the characterisation the metabolic status of tissue. Short-echo chemical shift imaging methods can provide information from metabolites with high signal to noise ratio. In ^{1}H-MRSI resonances specifically from choline (Cho, 3.2 ppm), creatine (Cr, 3.0 ppm) and N-acetylaspartate (NAA, 2.0 ppm) are researched and compared. For diagnosis and prognosis of tumor tissue, significant signals also come from mobile lipids (Lip, 0.9 - 1.4 ppm), which are linked to the necrotic process. Lactate (Lac, 1.3 ppm) serves as an important marker of the energy status and the oxygen supply of cells. The detection of lactate is made especially difficult by the presence of co-resonant lipid resonances. To overcome this problem, many editing sequences have been developed which use J-difference editing [1], polarization transfer [2] or multiple quantum filters to separate lactate from lipids. Some of them provide lipid suppression and simultaneous detection of lactate and choline / creatine resonances in a single scan to minimize motional and instrumental artefacts.[3-4] A drawback of these single-shot editing methods is the signal loss from mobile lipids. In this work, we combine short echo MRSI with the Selective Multiple Quantum Coherence filter (Sel-MQC) [5] to obtain the full ^{1}H metabolite spectrum and the edited lactate signal in one scan.

Material and Methods: Experiments were carried out on a Bruker 17.6 T widebore spectrometer equipped with a 200 mT/m gradient system. For RF transmission and detection, a 38 mm birdcage resonator was used. The pulse sequence is shown in Fig.1. It consists of a typical MRSI sequence: optional outer volume saturation (OVS) and water suppression (WS), followed by a 90° slice selective pulse, phase encoding and signal-acquisition (AQ 1). At the end of the detection period, the phase encoding is rewinded and the lactate editing sequence (Sel-MQC) for spectroscopic imaging described by He et al [5] follows. The 90°CH pulses selectively excite the lactate CH group at 4.1 ppm and the 180°CH_3 pulse refocuses the 1.3 ppm lactate CH_3 group. The ZQ -> DQ pathway was selected with gradient combination G1:G2 = -1:2. The lactate signal is acquired in a second acquisition window (AQ 2). The timing of the sequence is defined by the J-coupling of lactate. The first selective 90°CH pulse is applied $\tau = 1/2J = 69$ ms after the initial 90° pulse. The signal acquisition in AQ 1 can therefore be 60 ms to 65 ms, depending on phase encoding duration, which is enough for most in-vivo experiments. The sequence was tested on a phantom and a post-mortem (two hours) mouse brain. The phantom was made up consisting of a large (20 mm) tube filled with distilled water. Three 5 mm tubes were placed in the lager tube; the first containing 100 mM lactate, the second 50 mM choline and 50 mM creatine (all in aqueous solution), and the third sunflower oil. Water suppression was achieved with the VAPOR suppression scheme [6] using hermite pulses of 120 Hz (FWHM). After a phase encoding time of 1.5 ms, the signal was recorded for 62.4 ms (512 points) in AQ 1. For the selective 90°CH pulse, a hermite shape (7 ms, FWHM = 675 Hz), for the 180°CH_3 a sinc3 shape (5 ms, FWHM = 930Hz) was used. TR = 1s, AQ2 = AQ1. To avoid side-lobe effects from the spatial response function and contamination from surrounding areas, an acquisition-weighted k-space sampling (Hanning) was applied.[7] For the phantom, the number of total scans (NS) was 1500, resolution = 0.85 mm x 0.85 mm in plane and slice thickness = 1 mm. Parameters for post-mortem mouse brain experiment: TR = 1.5 s, NS = 1200, resolution = 1.6 mm x 1.6 mm in plane, 2 mm slice.

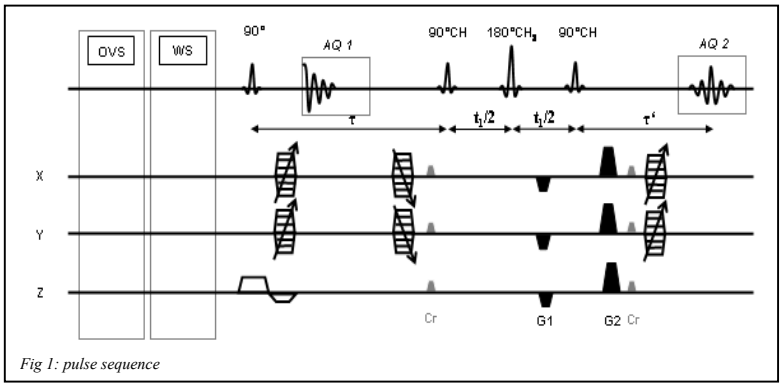

Fig 1: pulse sequence

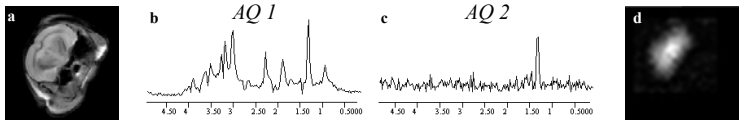

Fig 3: mouse brain post-mortem: (a) reference, (b) full spectrum, (c) filtered spectrum, (d) lactate map (AQ 2)

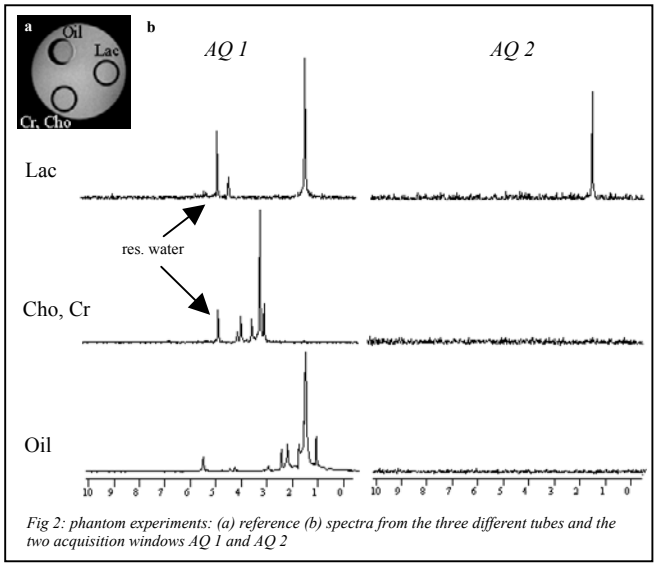

Fig 2: phantom experiments: (a) reference (b) spectra from the three different tubes and the two acquisition windows AQ 1 and AQ 2

Results and Discussion: Fig. 2a shows a RARE-reference image of the phantom. Spectra acquired from the different tubes of the phantom and the two acquisition windows (AQ 1, AQ 2) are displayed in Fig. 2b. For better visualisation of the metabolites, the spectra are not scaled identically. In AQ 1, all metabolites are observed, while in AQ 2 only the edited lactate signal is refocused and other resonances are dephased. In Fig. 3a, the RARE-reference image of the mouse, in Fig. 3b, 3c the two acquisition spectra from a voxel in the brain are shown. The reconstructed lactate map of AQ 2 is shown in Fig. 3d. The apparent signal loss of the lactate from AQ 1 to AQ 2 is caused by the Sel-MQC filter, which only refocuses half of the lactate signal, T2 relaxation, and diffusion effects in presence of gradients. The Sel-MQC sequence requires selective pulses and good frequency excitation. This necessitates long pulses that increase the t1-period of the sequence and some additional loss of lactate signal. The advantage of the high field could be used (^{1}H resonance frequency = 750 MHz, chemical shift difference of the lactate CH and CH_3 group is about 2100 Hz), by short selective pulses (5 ms) without interference. Care must be taken about the water suppression: the bandwidth of the selective suppression pulses must be small enough not to contact the lactate CH group at 4.1 ppm.

Conclusion: Short-echo chemical shift imaging could be combined with a selective lactate filter, improving the metabolite information in a single shot. The sequence will be applied for lactate, choline, and lipid detection in different xenograft tumor-models. For fast tumor lactate imaging, we are working on a combination of the Sel-MQC filter with a RARE readout.

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