Refocused double quantum filter

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Introduction

Several multiple quantum coherence (MQC) filters have been proposed for the detection of compounds with J-coupled spin systems [1]. One of these compounds is lactate, which is used as a biomarker of anaerobic glucose metabolism, therefore applicable to many clinical areas, like oncology. The resonance of lactate is obscured by lipid signals or macro molecules having the same chemical shift (1.33ppm). Double quantum coherence (DQC) filters provide a superb suppression overlapping resonances due to asymmetric field gradients: during the t_1-time (fig 1) the lactate spin system is in a DQ state where it is twice as sensitive to a dephasing gradient. The signal has to be rephrased with a gradient twice the area during the last interval where the spin system is in a regular single quantum state. Not-coupled signals (e.g. water and lipids) in general do not have a DQ state, therefore the signal is spoiled.

Unfortunately DQC filters are always associated with signal loss of the metabolite of interest. At least 50% of the lactate signal is lost by selecting the double-quantum coherence pathway. There is however another cause of signal loss due to evolution of the spin system in the t_1-time which can be as much as $\cos^2(\pi\ J\ t_1)$. [2] As the t_1-time is mainly determined by the duration of the crusher gradient, this time should be minimized in order to reduce signal loss, but maximized to improve crushing ability [3]. Therefore detecting lactate remains challenging at low concentration or in lipid rich environment.

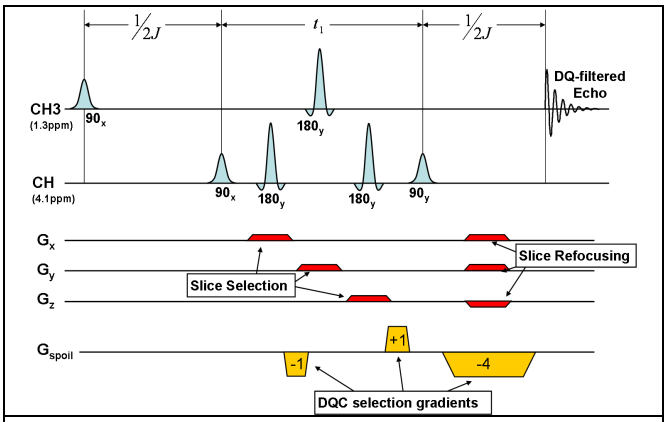

Figure 1. The rDQ filter; refocuses both J-coupling and chemical shift during the t_1 time period.

In this work we present a refocused DQ filter (rDQ) which prevents this additional signal loss. With the rDQ-filter, crusher gradients can be maximized, allowing detection of lactate at low concentration and in lipid rich environments.

Methods

Measurements were performed on a 7T whole body MR scanner (Philips). The rDQ filter is a variation on the SEL-MQC sequences proposed by He [2]. In SEL-MQC one refocusing pulse is aimed at either the CH3 group (SSEL) or on both groups simultaneously (HSEL), leading to signal loss with a factor of $\cos(\text{pi J } t_1)$ or $\cos^2(\text{pi J } t_1)$ respectively due to the fact that either chemical shift or the J-coupling is not refocused over the t_1 period. We propose the use of three selective refocusing pulses (figure 1) to refocus both chemical shift and J-coupling, thereby cancelling the term of additional signal loss.

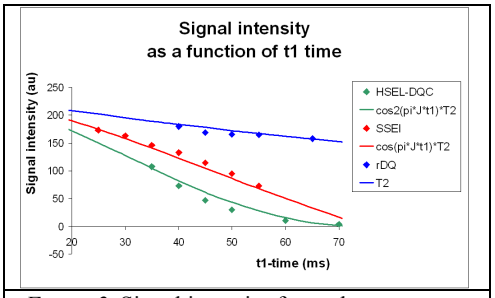

Figure 2. Signal intensity from phantom measurements (dots) and simulations (solid line) for SSEL-DQ filter (red), HSEL-DQ filter (green) and refocused DQ filter (blue) as a function of MQ time t1.

All RF pulses were 3ms long, 800Hz bandwidth. The three refocusing pulses were made slice selective to create a single voxel measurement. The low bandwidth of the slice selective refocusing pulses makes the pulses both spectrally and spatially selective.

DQ selection gradient duration for the in-vivo measurement was 8 ms (20mT/m), leading to an effective dephasing gradient of 2x8 ms for lipid signals. In the SSEL and HSEL sequence similar dephasing gradients would have led to signal loss of 33 and 55 percent respectively.

Results

Detection sensitivity as a function of t_1 time for the conventional SSEL and HSEL as well as with the proposed refocused DQ filter is shown in figure 2. The refocused filter is only sensitive to T2 decay where both conventional methods show severe additional signal loss dependent on the crushing gradient length expressed as the MQ evolution time t_1. Figure 3 shows an in vivo single voxel measurement of the brain of a healthy volunteer (4x4x4cm3 voxel, NSA=256,TE=194ms,TR=1s) where only signal from lactate (1.33ppm) was detected.

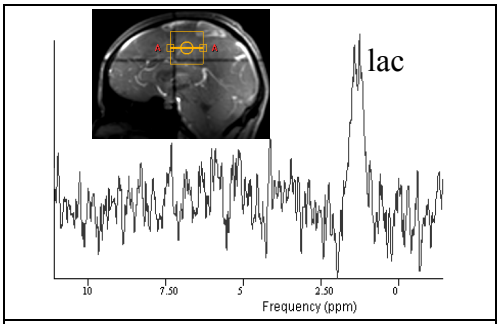

Figure 3. In-vivo brain lactate measurement with the rDQ-filter in a healthy volunteer. The low concentration lactate is visible at 1.3 ppm with complete suppression of all other signals.

Discussion and conclusion

We have shown with phantom measurements and quantum mechanical simulations that the proposed refocused DQ filter is, apart from T2 relaxation, insensitive to signal loss caused in the multiple quantum evolution time (t_1), thereby increasing the measurement sensitivity for DQ filters close to the theoretical 50%. The high sensitivity is demonstrated in vivo by a measurement of baseline lactate level in the human brain. All measurements were performed at 7T because of the high intrinsic detection sensitivity. It should be noted that for low-field application the refocused DQ filter might be effective as well, since the duration of the RF-pulses will be longer, lengthening the minimally required t_1 time even more.

1) Trabesinger MRI 2003; PMID: 14725936 2) He et al. J Magn Reson B. 1995; PMID: 7719620. 3) Mellon et al. MRM 2009; PMID: 19785016