Symmetric-sweep spectral-spatial RF pulses for spectral editing

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INTRODUCTION Spectral-spatial radiofrequency (SSRF) pulses [1] allow simultaneous selection in both frequency and spatial domains. These pulses are particularly important for magnetic resonance spectroscopy (MRS) applications where suppression of large water (and lipid) resonances is critical. Also, the high bandwidth of the sub-pulses (5-10 kHz) greatly reduces the spatial-shift errors associated with different resonant frequencies in MR spectroscopic imaging (MRSI) [2]. In this abstract we demonstrate a new design for non-linear-phase 180-degree SSRF pulses that can be used for spectral editing of lactate. The novel feature of the pulses is that the spectral profile develops as a symmetric sweep, from the outsides of the spectral window towards the middle, so that coupled components are tipped simultaneously and over a short interval.

THEORY Non-linear phase modulation has become an important tool in RF pulse design for enabling the use of pulses with shorter duration, while keeping the peak amplitude within the limits of the RF amplifier [3]. The amplitude of these pulses is spread much more evenly over the pulse duration in comparison to conventional, linear-phase pulses which are strongly peaked. The problem is that, by its nature, a non-linear phase RF pulse affects different resonant frequencies at different times during the RF pulse. These pulses perform poorly for J-difference editing because the coupled components, which have different frequencies, are tipped by the pulse at different times.

METHOD To test the new RF pulse design method, a symmetric-sweep pulse was computed for lactate editing at 3T. The pulse was designed to refocus a spectral window encompassing the 1.3ppm to 4.1ppm components of lactate. An important design criterion was to ensure that when the pulse was centered on this window, the two lactate resonances were affected simultaneously and over a short interval (<< 1/J). The new pulse was tested by acquiring MRSI data from a phantom containing metabolites of interest mixed with water. Experiments were performed on a GE Signa 3T whole-body scanner. The pulses were implemented in the PRESS pulse sequence. The parameters for the acquistion were: 8x8x8 phase encoding with 1cc voxels covering a 6cm x 6cm x 4cm volume defined by the selective RF pulses, TR=1s, TE=144ms, 512 samples per readout with 1kHz spectral bandwidth. The standard brain spectroscopy phantom provided with GE Signa scanners was used which contains choline, creatine, N-acetyl aspartate (NAA) and lactate.

RESULTS The RF pulse designed with the new method is shown in Fig.1. It is interesting to note that the sweep through the spectral dimension is reflected in the appearance of the RF waveform, with higher frequency oscillations of the sub-lobe amplitudes at the start of the pulse. The spectral sweep caused by the pulse is shown in Fig.2(c). To verify the functionality of this editing scheme, the relative height of the lactate peak was quantified. The peak height of lactate relative to NAA was calculated for 32 voxels in a central region of the volume. As an estimate of the true value, the ratio of lactate to NAA was also computed from the ``cycle B" spectra (e.g. Fig.3(b)), because in this cycle there is no modulation from the 4.1ppm component. The editing gave a mean lactate/NAA ratio of 0.197+/-0.018, and the estimate of truth gave 0.211+/-0.019 (the error values are the standard deviation of the 32 voxels). This experiment suggests that a 93% editing efficiency was achieved. This is consistent with the appearance of the residual lactate in Fig.3(d).

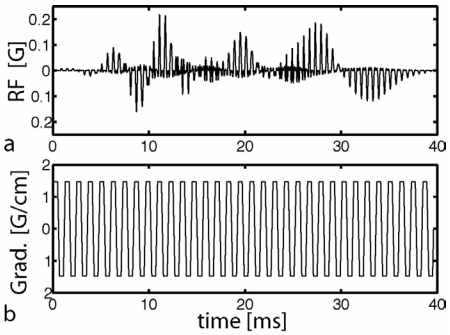

Figure 1: The RF (a) and gradient (b) waveforms for lactate editing at 3T. The sublobes were 600us in duration, with 66 sublobes covering the 39.6ms duration.

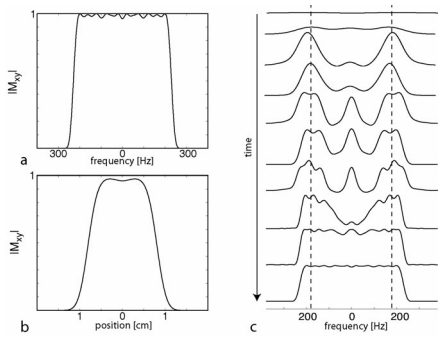

Figure 2: Performance of the symmetric-sweep RF pulse for lactate editing at 3T. The spectral and spatial selectivity are shown in (a) and (b), respectively. (c) The spectral profile of the pulse is plotted at ten equally spaced intervals (3.96ms apart) during the pulse. The two dashed lines denote the frequencies of the two components of lactate. The key to this pulse's usefulness for editing is that tipping occurs at these two frequencies simultaneously, and over a short interval.

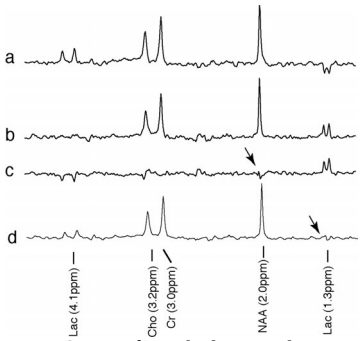

Figure 3: Data from the lactate editing experiment using the new pulse. Typical spectrum acquired with (a) both 1.3ppm and 4.1ppm components refocused and (b) 4.1ppm component excluded. The difference (c) shows a resolved lactate doublet at 1.3ppm, with some leakage (arrow). The sum (d) shows well-resolved peaks from choline (3.2ppm), creatine (3.0ppm) and NAA (2.0ppm), but with some leakage of the edited lactate doublet (1.3ppm).

CONCLUSIONS We have developed and demonstrated a new method for generating spectral-spatial 180-degree RF pulses for editing coupled spins. The main feature of the new pulses is that the spectral window is refocused in a symmetric sweep, from the outer edges of the window inwards, enabling the simultaneous refocusing of coupled spins. Also, the phase profile of the spectral window is non-linear, and the resulting savings in RF amplitude can be spent on high bandwidth in the spatial dimension (10kHz), minimizing the spatial offsets between different resonances. Phantom studies showed that lactate editing is feasible using the new pulses, with a 91%-93% editing efficiency. The performance of these pulses in vivo is currently being investigated.

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