

# MRSI localization at 7T based on frequency modulated RF pulses

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## Introduction

MR spectroscopy is one of the most promising applications of 7T human MR systems. Profiting from SNR gain as well as increased spectral resolution, detection and reliable quantification of an expanding number of metabolites and therefore a deeper insight into the human physiology becomes feasible. In order to take full advantage of the high field strength, technical challenges related to it have to be solved. A major limiting factor is the maximum achievable  $B_1$  field strength, resulting in a considerable decrease in bandwidth for conventional amplitude modulated RF pulses. In combination with the large increase in spectral separation, an undesirably strong chemical shift displacement artefact occurs, resulting in distorted metabolite ratios and inappropriate shimming and water suppression. It has been demonstrated that the bandwidth of an RF pulse can be significantly increased by spreading out its main lobe using frequency modulation. This work shows that the combination of frequency modulated excitation, refocusing and saturation pulses offers a flexible solution for precise MRS and MRSI localisation on 7T human MR scanners subject to strict  $B_1$  and SAR limits. Desirable spectral quality using PRESS, STEAM, or slice selection in combination with an optimized OVS sequence [1,2] can be achieved.

## Materials and Methods

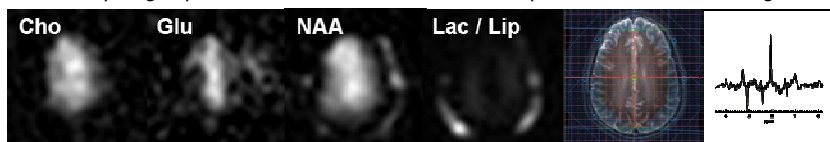
Frequency modulated excitation (fremex05) and refocusing (fmref07) pulses [3] created using an iterative design strategy [4] and saturation pulses with polynomial phase response (PPR) [5] based on the Shinnar-LeRoux transformation [6] have been implemented on a 7T Philips Achieva human MR system (Figure 1). Measurements were performed using a birdcage transmit-receive-head coil with a maximum  $B_1$  of 10  $\mu$ T. SAR was limited to 1.8 W / kg. Third order shimming was available.

## Results and Discussion

Considering the harsh  $B_1$  limitations on 7T human MR systems, the use of conventional amplitude modulated RF pulses for MRS / MRSI localization becomes unfeasible. The resulting strong chemical shift displacement precludes precise MRS / MRSI localisation and leads to distorted metabolite ratios, anomalous J-modulation effects, and artefacts arising from poor shimming and failed water suppression that appear as water side bands, ghosting, and line broadening (Figure 2a). The use of frequency modulated excitation (fremex05) and refocusing (fmref07) pulses improves the chemical shift displacement artefact significantly (Figure 2b). Saturation pulses with polynomial-phase response (PPR) achieve the highest bandwidth and show a negligible chemical shift displacement (Figure 2c).

The described frequency modulated excitation, refocusing and saturation pulses can be combined in a flexible way to suit the application. For long echo time MRS and MRSI, PRESS based on fremex05 and fmref07 can be used. At the cost of an increase in TR (and hence scan time) to stay within the SAR limits, over-prescribed PRESS, using the PPR pulses to saturate signal from non-overlapping areas of the shifting PRESS boxes, can be used to further improve the localisation. Resulting in vivo data demonstrate the precise localization, which enabled good shim and water suppression and correct metabolic information (Figure 3). Considering the significantly faster  $T_2$  relaxation at 7T, the signal of most metabolites has decayed at the minimum possible echo time of 73 ms using PRESS, which is a result of the long pulse duration of the refocusing pulse (Figure 1,3). To detect fast relaxing metabolites, STEAM with fremex05 pulses can be used. An alternative for MRSI localization is slice selection based on fremex05 in combination with an OVS sequence using PPR pulses with numerically optimized flip angle adjustment that takes into account  $T_1$  relaxation of lipid and band crossing [1,2]. Excellent lipid suppression combined with good adjustment to the anatomy makes metabolic information in cortex regions accessible. Direct acquisition of the FID retains the full SNR advantage of a 7T system and enables mapping of strongly J-coupled metabolites such as glutamate (Figure 4).

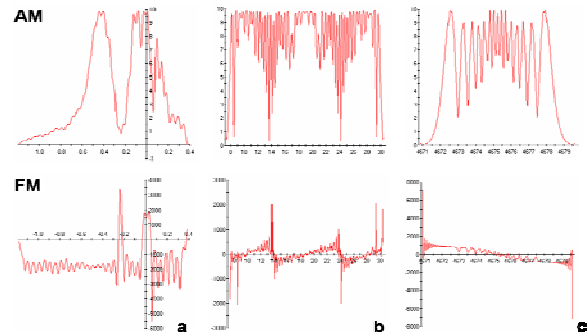
To match the strict SAR limits, typical repetition times for PRESS, slice selection with OVS, and over-prescribed PRESS are 3000 ms, 5000 ms and 6000 ms respectively. The selectivity of the PPR saturation pulses can be traded against scan time reduction, since for each flip angle, pulses with different time-bandwidth products have been designed.



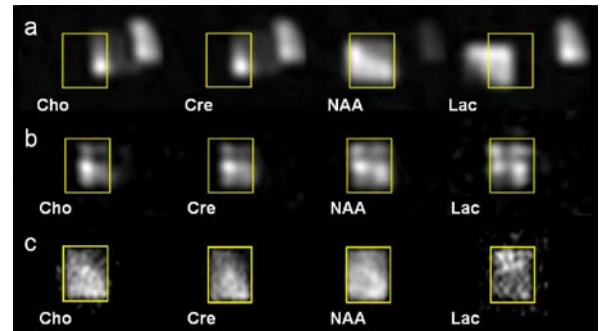
**Figure 4** slice selective MRSI localization in vivo using fremex05 for excitation and 2 cycles of 10 PPR saturation bands with numerically optimized flip angle adjustment considering OVS band crossings and  $T_1$  relaxation of lipid; direct acquisition of the FID retains the full SNR advantage of a 7T system and enables mapping of fast relaxing metabolites as Glutamate; metabolite maps are scaled to its individual maximum;

## References

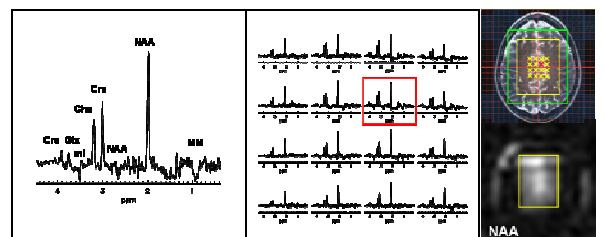
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**Figure 1** Utilized RF pulses scaled to  $B_1=10\mu$ T; **a)** excitation pulse fremex05, pulse duration: 11.7 ms **b)** refocusing pulse fmref07, pulse duration: 24 ms **c)** PPR saturation pulse, nBW = 500, flip angle = 90°, pulse duration: 8.7 ms;



**Figure 2** MRSI localization, Brain phantom,  $B_1=10\mu$ T **a)** PRESS with amplitude modulated excitation and refocusing pulses **b)** PRESS with frequency modulated excitation (fremex05) and refocusing (fmref07) pulses **c)** slice selective MRSI using the frequency modulated excitation pulse (fremex05) and 2 cycles of 6 PPR saturation pulses for OVS



**Figure 3** over-prescribed PRESS for MRSI localization in vivo combining fremex05, fmref07 and PPR saturation bands, TE = 73 ms; green – PRESS box, yellow – inner boundaries of OVS; 6 OVS pulses; OVS flip angles: 90°; 2 OVS cycles