Simultaneous up- and downfield spectroscopy using SPECIAL at 7T

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Introduction: The information content of the upfield (0–4.5ppm) and downfield (4.7–8ppm) spectral range in ^{1}H MRS is complementary [1-4], with specific diagnostic relevance for phenylketonuria [5] of the downfield range. Hence it is desirable to acquire metabolic information from the upfield and downfield resonances simultaneously with high regional specificity instead of solely considering upfield resonances. However, the detection of the downfield resonances is strongly compromised by their very weak signal intensities and short T_2 relaxation times. For this reasons usually very large voxel sizes, specifically tailored sequences and long scan durations are required. Another problem arising from acquiring full range spectra is the pronounced chemical shift displacement artifact at 3T and 7T that are caused by the limited pulse bandwidth due to B1 restrictions for human scans. **In this work**, a novel implementation of inner volume saturated [6], magnetization transfer compensated SPECIAL [7, 8] at 7T is presented that allows for regional specific, reproducible acquisition and quantification of up- & downfield metabolites in the human brain simultaneously.

Materials & Methods: A ^{1}H quadrature surface coil (max B_1 42uT; RAPID Biomedical) was used to acquire data from a voxel in the occipital cortex of 4 healthy volunteers on a Philips 7T Achieva Scanner (Philips Medical Systems, Cleveland). Volume based power optimization [11] and second order FASTESTMAP shimming were performed. SPECIAL [7] with a minimum echo time of 11.8ms and a repetition time of 7000ms was used for localization. Due to the small downfield signals 160 fids were acquired. The prescribed voxel size for SPECIAL was 29.5x24.3x23.4mm. The frequency offset of all applied RF pulses was set to the water resonance, which lead to a comparable but opposite chemical shift displacements (CSD) of lipid signal at 1.3ppm and downfield signals at 8ppm. The partial volume where downfield signals overlap with lipid signals spatially corresponds only to about 41% of the initially planned VOI. As shown in Fig. 1 six thin (20mm) higher order polynomial phase saturation pulses [10] were used to saturate the non-overlapping contributions of the chemical shift boxes resulting in an effective voxel size of 21.3x13.2x24.6mm. An additional 7th saturation pulse was used to eliminate residual outer volume lipids. The outer volume saturation pulses were interleaved with an optimized VAPOR water suppression sequence [10]. The SPECIAL inversion pulse was controlled to prevent artifacts from magnetization transfer and residual NOE effects [8]. The broad bandwidths of the used OVS pulses lead to a maximum chemical shift displacement between 1.3 and 8ppm which is lower than 2.5mm (see Tab. 1). Unprocessed data of the measurements were exported and all individual FIDs were coherently averaged. Prior to spectral fitting with LCModel [12] the small residual water was removed by an HLSVD filter. For the quantification a basis set using adjusted chemical shifts and coupling constants reported by Tkác [15] was simulated with the GAMMA library [14]. Four consistent downfield peaks were fitted in JMRUI [13].

pulse	BW [kHz]	chemical shift [%]		chemical shift [mm]	
		h20/fat	h2o/8ppm	h2o/fat	h2o/8ppm
ex	6.2	15.42	15.88	4.55	4.69
echo	3.9	24.25	24.98	5.89	6.07
inversion	13.7	6.96	7.17	1.63	1.68
OVS	15.8	6.05	6.23	1.21	1.24

Tab. 1: bandwidth of the pulses used for the inner volume saturated SPECIAL sequence together with their relative chemical shift displacement and absolute shifts for the 29.5x24.3x23.4mm planned voxel and 20mm rest slabs.

Results & Discussion: Even with relatively high B_1 values the bandwidth of commonly used excitation or echo pulses usually doesn't suffice to acquire full range spectra with reasonable chemical shift displacement. This might lead to a variety of different problems. For some metabolites like GABA, Glu or Lac the modulation patterns of their multiplets might change which can even lead to signal loss [6]. Concentration ratios might get distorted due to spatial differences in tissue composition and inhomogeneous B_1 field distribution in surface coils might lead to broad distribution of different flip angles depending on the specific offset frequency. It could be shown that SPECIAL together with an inner volume saturation scheme can be used to acquire spatially selective full range spectra with a very small chemical shift displacement. Fig. 1 shows the excellent spectral quality and reproducibility over all volunteers in the up- and down field part of the spectrum. In the downfield 4 major peaks (one being a NAA resonance) could clearly be identified and fitted. Additional peaks also show up at about 6ppm. Quantification results in Figure 3a & 3b also show good reproducibility even for small downfield peaks. Since high bandwidth saturation pulses with sharp transition regions were applied for additional localization purposes, more basic excitation and refocusing RF pulses shapes could be used to reduce the minimum echo time. This is especially important for the detection of downfield metabolites along with upfield metabolites that exhibit short T_2 relaxation times such as NAAG, GSH, glutamine or myo-Inositol.

References:

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[14] Smith et al., JMR A 106 (1994)
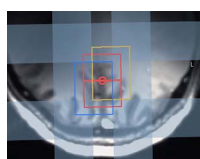[15] Tkác et al., Proc. 16th ISMRM 2008, #1624

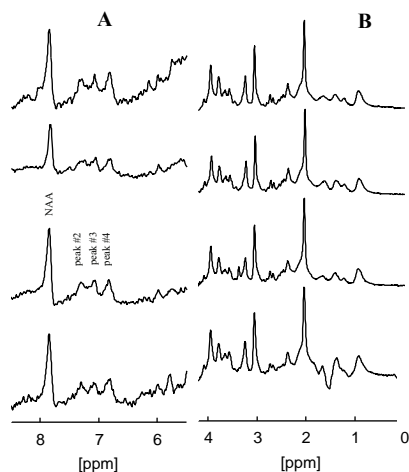*Fig. 1: planned voxel together with rest slab positions and chemical shift boxes for fat, water, 8ppm.*

Fig. 3a: fitting results in arbitrary units for the 4 downfield peaks as fitted by JMRUI. The error bars represent SD over all volunteers.

Fig. 2: (A) upscaled downfield spectra of all 4 volunteers and (B) the corresponding upfield spectra.
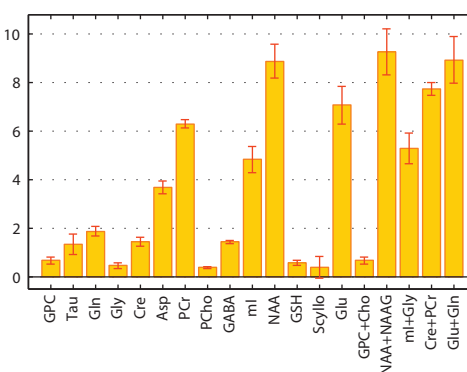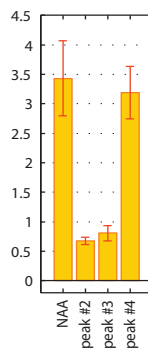
Fig. 3b: concentration ratios to the water signal (scaled by 10^5) as reported by LCModel for the upfield metabolites. Only metabolites with CRLB less than 20% were included in the plot. The error bars represent SD over all volunteers.