

Multi-slice MRSI of the human brain at 7 tesla using dynamic B_0 and B_1 shimming

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Introduction:

MRSI of the human brain at high field shows potential because of increased SNR and chemical dispersion at high field, however, coping with SAR limitations has shown due to high power deposition during outer volume suppression (OVS), water suppression (WS) and when using high bandwidth refocusing pulses for volume selection. Limitations for multi-slice MRSI are even more severe, since interleaving multiple slices will increase the RF power deposition further. Therefore, in this work a low power MRSI sequence was developed which now allows for multi-slice MRSI at 7 T, utilizing low power WS in the steady-state and RF shimming with an 8 channel coil for low power OVS. Slice-by-slice RF shimming and 3rd order dynamic B_0 shim updating (DSU) (1) was employed to boost B_0 and B_1 field homogeneity on a slice by slice basis. Pulse-acquire MRSI (2) was used to generate a short TE MRSI measurement with high SNR and low chemical shift displacement artifacts, resulting in high quality, high resolution multi-slice MRSI in the human brain within a reasonable scan time.

Methods:

Experiments were performed on a 7 T head-only MR system. The gradient system included a set of 3rd order shims with preemphasis compensation, essential for DSU of the high order shim coils (1). Data was acquired using an eight element circular transceiver array driven by an eight channel (8x1 kW) RF amplifier.

B_1 maps for RF shimming were obtained from gradient echo phase images and absolute B_1 maps acquired with the BS-method (3), with a total acquisition time of 9 minutes for the calibration of 8 channels on 5 slices (4x4x4mm³).

Sequentially the optimal RF phase and amplitude settings were calculated for 3 different modes of excitation on 1. slice-by-slice excitation of the skull without exciting the brain (ring mode) for OVS, 2. global brain excitation for WS, 3. slice-by-slice brain excitation RF shim for the 90° excitation pulse. The transmit phases and amplitudes were switched to the appropriate RF shim before every RF pulse (figure 1).

After RF shimming, some variation in B_1 remained, therefore both the OVS and WS were performed with a series of pulses with an effective suppression for a range of B_1 and T1 values which is achieved by numerical optimization of the flip angles and delays. OVS was performed with four slice selective pulses in the RF ring mode. Due to both the slice selection and RF ring selection, only the skull area on a single slice at a time was suppressed without perturbation of the magnetization in adjacent slices (30 fold suppression on average). WS was performed with four global frequency selective, low power Gaussian pulses. By taking the steady state behavior of the WS scheme into account during the optimization, an average 760 fold suppression was reached with four pulses per slice with insensitivity towards $\pm 50\%$ variation in B_1 and typical brain water T1 values.

DSU settings for a slice-by-slice B_0 shim updating to improve field homogeneity were calculated from a 15 slice B_0 map covering the volume of the multi-slice MRSI sequence.

The MRSI measurement consisted of a transverse, 5 slice acquisition with a slice selective pulse acquire method (figure 1) with a 25x25 circular phase encoding matrix. (TR/TE=2500/2.75ms, voxel size=8x8x8mm³, 5 slices, slice gap=2 mm). The RF power deposition of 2.3 \pm 0.3 W/kg (mean \pm SD, n = 5) was well within FDA guidelines. Residual water in the MR spectra was filtered out with an HSVD filter. The first missing data points (due to the acquisition delay) were extrapolated back to TE=0 for removal of first order phase effects on the displayed spectra.

Results:

3rd order DSU B_0 shim optimization of the B_0 field showed a reduced linewidth in substantial areas of the brain (figure 2a). Slice-by-slice optimization of the transmit B_1 field displayed a more homogeneous excitation of brain tissue (figure 2b). Suppression of water signal was measured to be highly effective (~ 500 fold) and lipid signals are sufficient reduced to 10 fold and 100 fold (figure 3). Based on signal intensity and linewidth measures, approximately 78% of the brain voxels were considered as high quality spectra (~ 700 voxels per dataset), two examples from one dataset are shown in figure 4.

Conclusion:

High resolution, short TE, multi-slice MRSI acquisition of the human brain has been shown, utilizing low power suppression of water and lipids. By using slice-by-slice B_0 and B_1 updating, high quality spectra on five slices in the human brain were acquired.

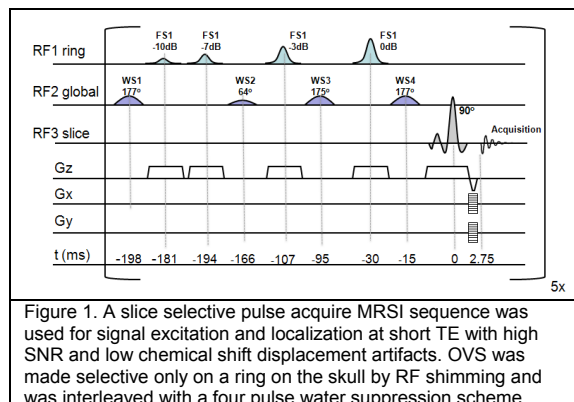


Figure 1. A slice selective pulse acquire MRSI sequence was used for signal excitation and localization at short TE with high SNR and low chemical shift displacement artifacts. OVS was made selective only on a ring on the skull by RF shimming and was interleaved with a four pulse water suppression scheme.

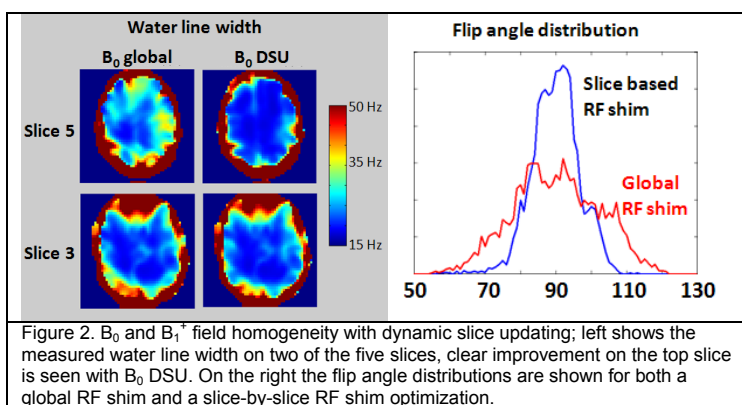


Figure 2. B_0 and B_1 field homogeneity with dynamic slice updating; left shows the measured water line width on two of the five slices, clear improvement on the top slice is seen with B_0 DSU. On the right the flip angle distributions are shown for both a global RF shim and a slice-by-slice RF shim optimization.

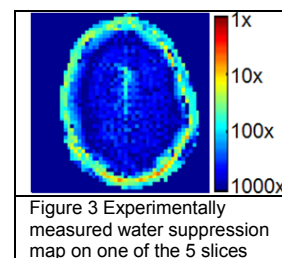


Figure 3 Experimentally measured water suppression map on one of the 5 slices

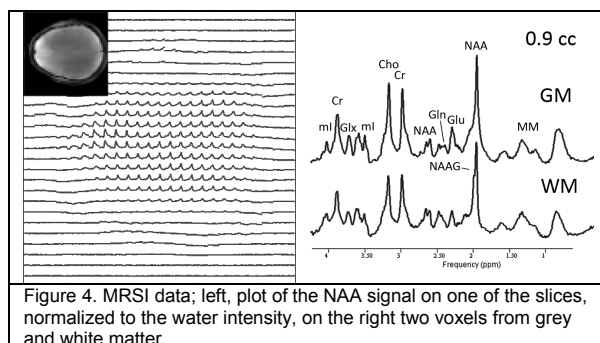


Figure 4. MRSI data; left, plot of the NAA signal on one of the slices, normalized to the water intensity, on the right two voxels from grey and white matter.

(1) Juchem et al. *Concepts Magn Reson Part B*, 37B:116 (2) Henning et al. *NMR in Biomedicine*, 22:683 (3) Sacolick et al. *MRM*, 63:1315