Mechanisms of SNR Enhancement and Line Shape Improvement in B_0 Correction for Overdiscrete MRSI Reconstruction

Thomas Kirchner[1], Ariane Fillmer[1], Klaas Paul Pruessmann[1], and Anke Henning[1,2]

[1]Institute for Biomedical Engineering, UZH and ETH Zurich, Zurich, Switzerland, [2]Max Planck Institute for Biological Cybernetics, Tuebingen, Germany

Introduction

Spectral line width and signal-to-noise ratio (SNR) are crucial performance markers for Magnetic Resonance Spectroscopic Imaging (MRSI). It is only with sufficient SNR and effective spectral resolution that reliable metabolite quantification is enabled. B_0 correction at the subvoxel level [1] removes spectral shifts introduced by local static magnetic field distortions on an intermediate spectroscopic image with higher-than-nominal spatial resolution when target-driven overdiscrete reconstruction is used for the optimization of the spatial response function [2]. ***In this work***, we show improvements in line width and SNR following this reconstruction strategy, explain the mechanisms behind the effects and demonstrate complementarity to the conventional noise reduction and resolution enhancement method of limiting the acquisition time and zero-filling the FID signal to obtain the appropriate spectral resolution.

Theory and Methods

Data Acquisition: A 7T MR system (Philips Healthcare, Cleveland, USA) was used in conjunction with a head volume transmit/receive coil (NOVA Medical, Wilmington, USA) to record a 2D MRSI data set of a healthy volunteer's brain (field of view = 200x160x10 mm^3, nominal resolution 20x16 voxels). The slice had slightly angulated transverse orientation and was located in the area above the ventricular system. For demonstration purposes and despite suboptimal time-efficiency, highly efficient spatially selective lipid suppression was endeavored by using the FIDLOVS sequence which combines outer volume suppression with VAPOR water suppression and direct FID acquisition [3] (acquisition delay t_E=3.5ms, flip angle 90°, repetition time TR=7000ms, sampling duration 1024 ms, spectral bandwidth 4000 Hz). A second acquisition without water suppression was added. B_0 shimming was performed using advanced image-based shimming [4], however due to temporary hardware restrictions the optimum could not be reached. This led to the B_0 inhomogeneity pattern shown in Fig. 1 which is nonetheless not an uncommon situation.

Reconstruction: The target-driven overdiscrete reconstruction operator $F' = E^H(EE^H + \alpha\Psi)^+$ [5] yields a high-resolution, low-SNR intermediate spectroscopic image, if the encoding E is formulated on a higher-than nominal spatial resolution grid. Ψ is the noise covariance serving as a regularization term. After correction for spectral shifts based on the B_0 map, a Gaussian SRF target [2] is applied, performing spatial averaging to yield the target resolution of 20x16 voxels. This procedure was repeated with the FIDs set to zero after 512 ms, 256 ms, 128 ms and 64 ms (zero-filling).

Spectral Processing: After reconstruction of the water-suppressed and non-water suppressed spectroscopic imaging data sets, the former were eddy-current corrected by the phase of the latter [6]. The Voigt line shape model $S(\omega) = a\left[\left\{\exp\left(-\frac{(\omega-\omega_0)^2}{2\sigma^2}\right)/(\sigma\sqrt{2\pi})\right\} * \{1/(\gamma^2+(\omega-\omega_0)^2)\}\right] + c$ was fitted to the absolute water peak to obtain an estimate of line width and position. Here, $*$ is the convolution between the Gaussian and Lorentzian components with widths σ and γ, respectively, around the peak center ω_0.

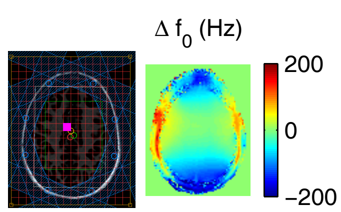

Figure 1: *MRSI slice planning with OVS slabs and residual B_0 inhomogeneity after shimming*

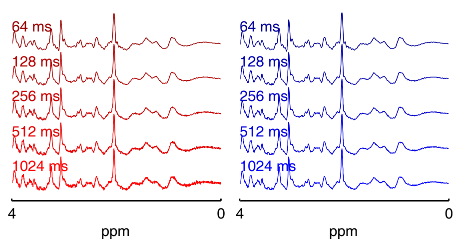

Figure 2: *Reconstructed in vivo spectra after eddy current correction from a central voxel without (red) and with (blue) B_0 correction after additional phase correction*

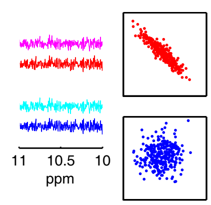

Figure 3: *Noise decorrelation between adjacent subvoxels in the center of the FOV before (red) and after (blue) spectral shifts; full sampling duration*

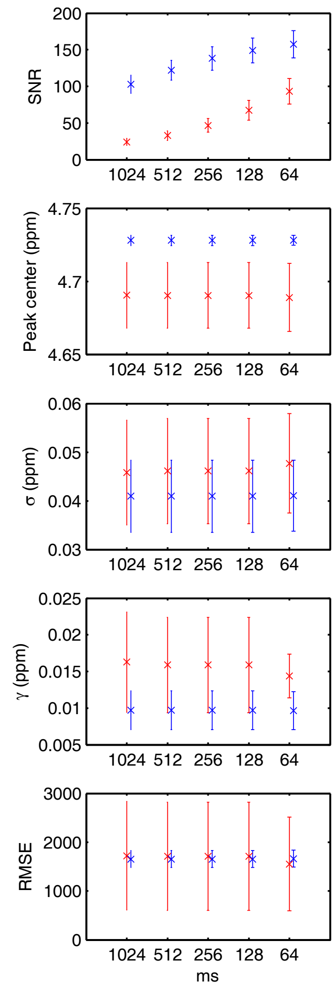

Figure 4: *Mean and standard deviation (total length of error bar) of the brain voxels for SNR and water peak fit parameters without (red) and with (blue) B_0 correction*

Results

An example spectrum from the voxel position indicated in Fig. 1 is shown in Fig. 2. Mean and standard deviation of SNR in all brain voxels (quantified as the ratio between the maximum of the absolute NAA peak at 2.0 ppm and the root mean square of the residual of a linear fit to the real part between 10 and 11 ppm) is shown in Fig. 4 (top). SNR improvement is obvious with B_0 correction and, in all investigated cases, adds to the SNR increase achieved by optimizing the acquisition time in combination with zero-filling (Fig. 2 and 4 top). Mean enhancement factors up to five were achieved and a strong dependency of the voxel based SNR enhancement on the voxel location was observed. The mechanism behind this additional SNR enhancement is the destruction of the pre-existing noise correlation between adjacent subvoxels which occur during overdiscrete reconstruction (Fig. 3). In addition to the SNR enhancement, the proper frequency alignment of peaks at the subvoxel level leads to better constructive spatial averaging. Independent of the zero-filling strategy, the water peak is hence better approximated (root mean square error, RMSE) by the theoretical Voigt line, and is narrower (smaller σ and γ fit parameters), which in turn enhances the effective spectral resolution (Fig. 4).

Conclusion

When using overdiscrete reconstruction, SNR enhancement is achieved with B_0 correction due to intra-voxel noise decorrelation. Furthermore, this enhancement is potentially bigger than with acquisition time optimization plus zero-filling. The two strategies may potentially be used in combination to further enhance SNR gain. This reduces the danger of cutting off valid signal and introducing truncation artefacts by premature zero-filling. On top of that, metabolite line width and shape improvements are typically observed due to the constructive spatial averaging of properly frequency-aligned spectra, which in turn enhances the effective spectral resolution. At the time of acquisition, only the (mostly negligible) effort of recording a B_0 field map is required in order to benefit from the stated improvements.

References

[1] T Kirchner *et al.*, ISMRM 2014 #2874
[2] T Kirchner *et al.*, MRM 2014 doi: 10.1002/mrm.25185
[3] A Henning *et al.*, NMR Biomed, **22** (2009) 683
[4] A Fillmer *et al.*, MRM. 2014. doi: 10.1002/mrm.25248
[5] KP Pruessmann and J Tsao, US Patent No. 7.342.397
[6] U Klose, MRM **14** (1990) 26