Overdiscrete Correction of B_0 Inhomogeneity in Accelerated ^{1}H FID-MRSI at 7T

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Introduction

In Magnetic Resonance Spectroscopic Imaging (MRSI), typical spatial resolutions are low compared to imaging. Limited k-space coverage leads to the voxel bleeding effect which causes the spectrum in a given voxel to contain contributions from other areas of the Field of View (FOV) to a certain extent. This constitutes an error source for metabolite quantification, especially since such contributions are not necessarily obvious from the appearance of the spectrum. To that end, Target-Driven Overdiscretized Reconstruction has been introduced, where the Spatial Response Function (SRF) is analyzed and optimized directly [1, 2]. It takes intra-voxel variations of receive coil sensitivities into account and thus improves spatial specificity and, if SENSE-acceleration by k-space undersampling is employed, the unfolding performance. Additionally, and despite the use of advanced B_0 shimming techniques, residual B_0 variations may remain, which act as additional encoding mechanism. Conventionally, they are corrected for by shifting the resulting spectrum by the appropriate frequency offset. Just like receive coil sensitivities, however, the variation of B_0 is a continuous function of space and thus varies even within the extent of a given voxel. This in turn leads to a position dependence of the spectral zero order phase, which is heavily susceptible to uncertainties in the resonance frequency. Since any voxel spectrum is the result of a spatial average as described by the SRF, incoherent spectral averaging may thus be expected that reduces SNR and leads to line broadening. ***In this work***, we extend our previously introduced MRSI reconstruction method to directly consider residual B_0 variations in a quasi-continuous manner to enable coherent spectral averaging across the spatial extent of the SRF.

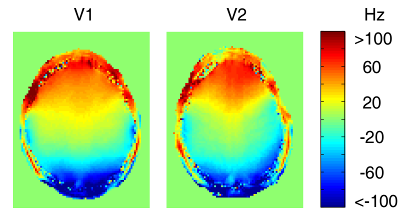

Figure 1: *B_0 maps after image-based shimming for volunteers 1 and 2.*

Theory and Methods

Data Acquisition: ^{1}H MRSI data sets from two healthy volunteers (V1, V2) were recorded at 7T (Philips Healthcare, Cleveland, USA) with a 32 channel head coil (NOVA Medical, Wilmington, USA) using the FIDLOVS sequence incorporating VAPOR water suppression, outer volume suppression and direct FID acquisition [3] (FOV: 200x160 mm^2, nominal voxel size 10x10x10 mm^3, nominal resolution N_π=20x16, acquisition delay t_E=3.47ms, flip angle 90°, TR=8000ms). For V2, fourfold SENSE [4] acceleration (R=2 in AP and R=2 in RL direction) and a non-water suppressed second acquisition was done. Data from V1 were retrospectively undersampled to yield the same acceleration factor. In both cases, image-based B_0 shimming was performed [5], in the given experiments leaving unusually large residual B_0 variations.

Reconstruction: In Target-Driven Overdiscretized Reconstruction, the operator F transforming k-space data to the grid of N_π target voxels is given by $F = TF'$ and $F'=\Theta E^H(E\Theta E^H + \alpha\Psi)^\dagger$, where E is the SENSE encoding operator expressed on a spatial grid ζ^2 more highly resolved than the nominal MRSI resolution. In this application, we used ζ=5 and a Gaussian target T. Ψ and Θ describe the noise covariance and spatial SRF prioritization, respectively; the free regularization parameter α was kept constant at 1. For Θ, a mild prior giving fivefold SRF optimality weight to the peripheral lipid region compared to the brain region was used as proposed in [6,7]. An intermediate spectroscopic image is now extracted after application of F', similar in spirit to Ref. [8]. It contains ζ^2 low-SNR spectra per target voxel that are then individually B_0-shifted by multiplying the FID with $\exp(-i2\pi\Delta f(\boldsymbol{r})[t+t_E])$. Here, $\Delta f(\boldsymbol{r})$ corresponds to the local B_0 field offset remaining after shimming. Finally, T is applied to the intermediate image.

Spectral Processing: All spectra were corrected for baseline distortions and manually phase-corrected but no spectral apodization was performed. In the case of V2, additional eddy current correction [9] was performed with the water reference scan reconstructed in the same manner as the metabolites.

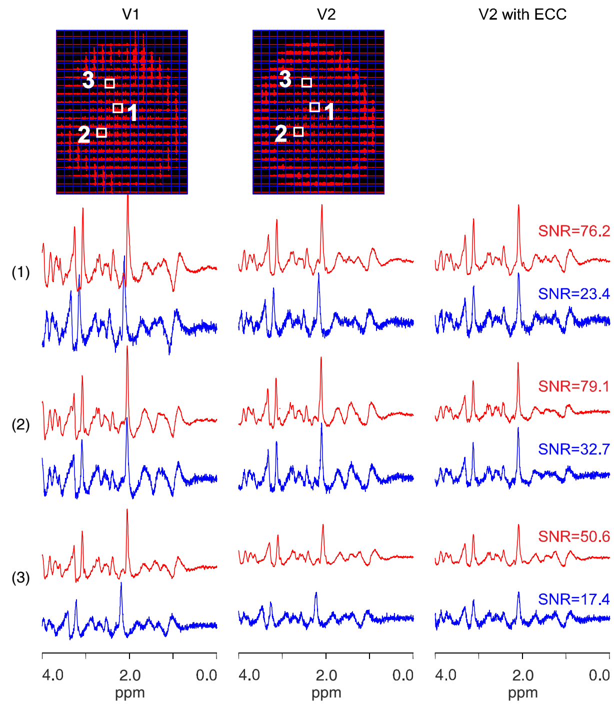

Figure 2: *Three representative spectra without (blue) and with (red) quasi-continuous B_0 correction. For V2, eddy current correction (ECC) was applied in addition. The real part after baseline and manual phase correction is shown. Note that no spectral apodization was performed. The SNR in the third column is estimated as the ratio between the modulus NAA peak amplitude and the root mean square of the real part between 10 and 11 ppm.*

Results

In Fig. 1, the B_0 maps are shown. Considerable variations over the FOV remain after B_0 shimming. A selection of voxel spectra from various locations of the MRSI without and with our proposed B_0 correction is displayed in Fig. 2. With conventional voxel-wise B_0 correction, a mere shift in the spectral domain would result. Since in our proposed method, this shift is performed on the intermediate high-resolution spectroscopic image for each subvoxel separately, the final spatial averaging as represented by the SRF occurs over spectra which are already frequency and phase aligned and is thus coherent. This is in analogy to coherent time averaging in single-voxel spectroscopy [10]. As a result, not only the desired frequency alignment between spectra of the final voxel grid but an additional gain in SNR is achieved (Fig 2, red). The mean SNR in the central 6x6 voxels increased by 2.77 in V2 after eddy current correction.

Conclusion

We extended the previously demonstrated Target-Driven Overdiscretized MRSI reconstruction approach to take B_0 fluctuations into account in a quasi-continuous manner. A substantial SNR gain and line width reduction is achieved, which would not be possible if only conventional, voxel-wise frequency correction was applied.

References

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