Characterization and correction of modulation sidebands in 1H MRS without water suppression by spatiotemporal field monitoring

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Introduction

Highly efficient water suppression schemes such as WET or VAPOR [1] are widely considered a prerequisite for state-of-the art in-vivo ^{1}H magnetic resonance spectroscopy (MRS). However, there are multiple motivations for ^{1}H MRS without water suppression: (1) the water signal needed for absolute quantification based on the internal water reference method as well as eddy current and phase corrections can be acquired without additional scan time; (2) efficient water suppression schemes have been shown to cause saturation transfer effects especially for resonance lines appearing downfield of water; (3) resonance lines that appear close to the water resonance such as glucose or lactate might be observed since they are not suppressed and (4) a time consuming iterative water suppression optimization is not necessary. The feasibility of in-vivo ^{1}H MRS without water suppression has been demonstrated with regard to the dynamic range of analog-to-digital conversion. However, modulation sidebands, which are introduced as a pair of anti-phase peaks placed equidistantly to the right and left of the water resonance by gradient-vibration-induced B_0 field oscillations, hamper metabolite quantification. To overcome this problem, a number of post-processing approaches, gradient inversion schemes [2] and subtraction schemes based on frequency selective inversion pulses [3] have been devised. All robust approaches require either modifications to the existing spectroscopy sequence or cannot be combined with MRS imaging. ***In this work***, it is therefore proposed to characterize modulation side bands that are caused by gradient vibrations with the help of spatiotemporal field monitoring [4]. More specifically it is investigated whether calibration data acquired with a recently proposed field camera [5] permit the prediction and direct correction of modulation sidebands in ^{1}H MRS data acquired without water suppression.

Materials and Methods

Measurements were performed using Philips Achieva 3T and 7T human MRI scanners. At 7T field monitoring data were acquired using an adopted version of the initially reported field camera [5] during a typical spectroscopy sequence with the following parameters: STEAM, TE = 18ms, TR = 5000ms, voxel size: 20x20x20 mm, 2 averages, VAPOR water suppression. 35 repetitive scans with individual acquisition times of 32 ms were acquired in a sliding window fashion to monitor the entire acquisition period typically used in a spectroscopy exam. During every second average of each dynamic all gradients were inverted to investigate the related effect on B_0 field oscillations and the efficiency of gradient inversion based modulation sideband cancellation schemes.

At 3T, in-vivo ^{1}H MR spectra were acquired from the human visual cortex using a ^{1}H transmit/receive volume head coil and the following sequence parameters: PRESS, TE = 31.8ms; TR = 2100 ms; 128 averages; volume size: 15x15x15 mm; 2nd order FASTERMAP shimming. Subsequently calibration data were acquired with a field camera [5] during a repetition of the exact same sequence. All relevant gradient, shim, and F_0 settings were equally kept the same. The positions and baseline frequency offsets of the field probes were assessed by additional FID acquisitions with and without static gradients. As detailed in Ref. [4], the time dependence of the phase coefficients $k_0(t)$, $k_x(t)$, $k_y(t)$ and $k_z(t)$ (Fig. 2) for each original spectroscopy scan can be calculated from the field-probe data. Considering the position (x,y,z) of the spectroscopy voxels the local time evolution of the phase distortion φ can be induced according to:

$$\varphi(r,t) = k_0(t) + x * k_x(t) + y * k_y(t) + z * k_z(t) \quad (1)$$

Subsequently the modulation sideband artefact in the original spectra can be corrected in the time-domain signal s(t) according to:

$$s_{corr}(t) = s(t) * e^{(-i\varphi(r,t))} \quad (2).$$

Results and Discussion

Phase oscillations related to gradient vibrations could clearly be observed in the spatiotemporal field monitoring data acquired at 7T as shown in Figure 1a. Gradient inversion was reflected by the inversion of the monitored phase distortions. Hence adding the original data set and that obtained with inverted gradients enables perfect cancellation of these phase distortions (Fig. 1b) and thus of the related modulation sidebands as reported previously [3]. Based on these initial monitoring results the feasibility of direct correction of modulation sidebands was investigated. Demodulation of the original time-domain data by the measured phase perturbation (Fig. 2) indeed reduced the number and amplitude of modulation sidebands significantly as shown in a visual cortex spectrum (Fig. 3), which was acquired at 3T without water suppression. Nevertheless, a number of minor modulation sidebands remained, hampering the evaluation of this spectrum in the range of interest between 0 and 4 ppm. **In conclusion**, it has been shown that spatiotemporal field monitoring with an NMR field camera permits recording field oscillations caused by gradient vibrations and thus facilitates the assessment of compensation schemes such as gradient inversion. As demonstrated in a preliminary implementation it also holds potential for direct correction of modulation sidebands in ^{1}H MR spectra acquired without water suppression. The present feasibility study has been based on separate monitoring and spectroscopy measurements and is limited to a first-order spatial phase model. Concurrent monitoring of each individual spectroscopic acquisition and higher-order phase models are expected to render this approach even more accurate and are currently under investigation.

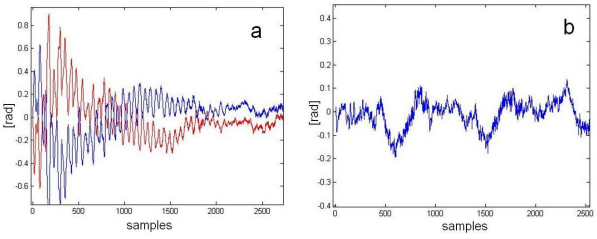

Figure 1: The phase evolution of the signal detected by an NMR field probe reveals high-frequency field oscillations (a, blue) caused by gradient vibration. The effect was inverted (a, red) by inverting the underlying gradients. The vibration effect is eliminated by adding the two phase evolutions (b).

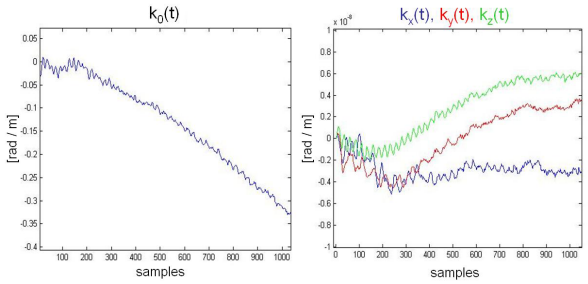

Figure 2: Phase coefficients as measured by spatiotemporal field monitoring at 3T.

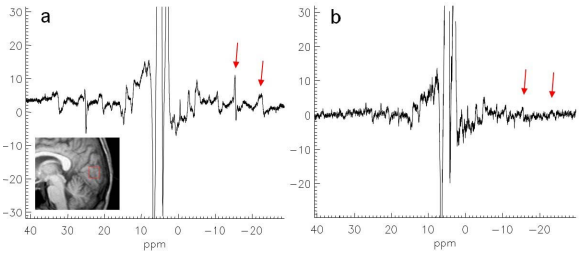

Figure 3: Modulation sidebands in a ^{1}H spectrum acquired in vivo without water suppression. (a) before, (b) after correction based on field probe data.

[1] Tkac I, et al., Magn Reson Med (41): 649-56; 1999 [2] Dong Z et al MRM (51): 602-606; 2004 [3] Dreher W et al, MRM (54) : 190-195 ; 2005 [4] Barmet C et al, MRM (60): 187-197; 2008
[5] Barmet C et al, ISMRM 2009; 781