Localization Errors in MR Spectroscopic Imaging Due to the Drift of the Main Magnetic Field and their Correction

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Target Audience

Clinical and basic researchers carrying out spectroscopic imaging experiments.

Purpose

Temporal instabilities of the spins' resonant frequency have long been recognized as sources of artifacts in various applications ranging from MR spectroscopy to thermometry and fMRI (1, 2). Over sufficiently long (many minutes) scans, the resonance frequency undergoes a predominantly linear shift, referred to as field "drift", due to tiny dissipative losses in the superconducting coil, typically on the order of ~ 0.1 ppm/hour. A detailed theoretical analysis of the Fourier reconstruction process (not presented) shows that, unlike in single-voxel MRS [3], field drift does not broaden spectral lines, but rather introduces localization errors, equivalent to spatial averaging due to a moving filter. We have set out to (i) quantify the drift and its effects in phantom and in-vivo and (ii) propose an efficient method for its correction.

Methods

The experiments were done in a 3 T TIM-Trio and a 1.5 T Avanto full body MR imagers (Siemens AG, Erlangen Germany). 3D CSI sequence was carried out in a phantom (TR=2.2 s, matrix size: $10\times10\times10$, FOV: $200\times200\times200$ mm^3, TA: 36.6 mins), and 2D PRESS-CSI was carried out in 10 healthy volunteers at 1.5T and 3T in an axial slice containing the ventricles (VOI: $80\times80\times10$ mm^3, FOV: $240\times240\times10$ mm^3, TR/TE=3000/60 ms, TA: 28.8 mins). The phantom was a 1.6-cm water sphere, entirely contained in a single voxel at the FOV's center. Both sequences were interleaved with a small tip angle, non localized pulse-acquire module which acquired a 10 ms FID. The water peak's frequency was estimated from its phase using a weighted least squares estimator, giving greater weight to points having a greater SNR ($t_n=n\Delta t$, Δt = dwell time, ϕ_n = phase of water FID, σ_n = SNR of nth point):

$$\hat{v} = \frac{1}{2\pi}\left[\left(\sum_{n=0}^{N-1}\frac{t_n}{\sigma_n^2}\right)\left(\sum_{n=0}^{N-1}\frac{\phi_n}{\sigma_n^2}\right) - \sum_{n=0}^{N-1}\left(\frac{t_n\phi_n}{\sigma_n^2}\right)\left(\sum_{n=0}^{N-1}\frac{1}{\sigma_n^2}\right)\right] \Big/ \left[\left(\sum_{n=0}^{N-1}\frac{t_n}{\sigma_n}\right)^2 - \sum_{n=0}^{N-1}\left(\frac{t_n^2}{\sigma_n^2}\right)\sum_{n=0}^{N-1}\left(\frac{1}{\sigma_n^2}\right)\right]$$

This estimator is efficient, i.e. its variance attains the Cramer Rao lower bound; this efficiency allowed for the relatively short FID digitization time (10 ms).

Results

The drift in the phantom was measured to be 18.4 Hz/hour. Results before and after drift correction are shown in Fig. 1. In volunteers, the drift was 0.12±0.05 ppm (mean±standard deviation over all volunteers). The drifts were linear to an excellent approximation, with a quadratic fit $v(t)=\alpha_0+\alpha_1 t+\alpha_2 t^2$ yielding a ratio $(\alpha_2\cdot T)/\alpha_1=0.15\pm0.09$ (mean±standard deviation). Fig. 2 showcases results from a sample volunteer at 3T.

Figure 1. The effects of drift in a phantom, before (top) and after (bottom) drift correction, along a fixed spatial index in the data matrix. Note the phantom, a 1.6 cm in diameter water sphere, is entirely contained within a single voxel at the FOV's center.

Discussion

In both phantom and volunteers, considerable distortions are observed due to the effect of drift. As both figures clearly showcase, the error is one of localization and not of broadening, as each voxel's signal is modulated by the signals in its proximity; broadening can be observed if the environment is inhomogeneous or has a discontinuity, as is the case, e.g., close to the ventricles. Drift correction (by frequency-shifting each FID prior to Fourier-reconstruction) mitigates the distortion.

Conclusion

Contrary to single-voxel MR spectroscopy, where it leads to line broadening, field drift can lead to localization errors in the longer chemical shift imaging experiments. Fortunately, this drift can be obtained at a negligible cost to sequence timing, and corrected for in post processing.

References

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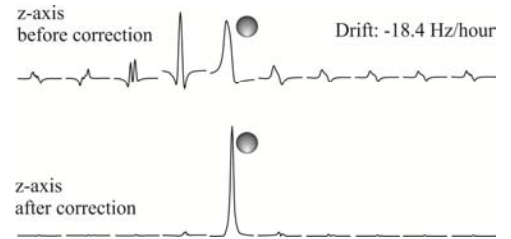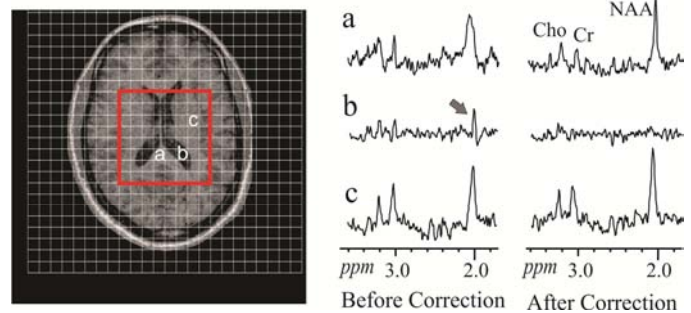
Figure 2. The effects of drift in-vivo, showcasing enlarged spectra from three voxels (a-c) before and after drift correction. The drift was quantified to be approximately linear (22 Hz/hour) using the interleaved FIDs and Eq. (1). Voxels (a) and (b), close to the ventricles, show spectral degradation due to the PSF's spatial "moving average" (Eq. 1). In particular, the ventricles (b) show spurious signals. On the other hand, voxel (c) is relatively unaffected as it is surrounded by similar voxels.