

# Spectral Registration: A simple new method for frequency and phase drift correction of magnetic resonance spectroscopy data

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**Introduction.** *In vivo* magnetic resonance spectroscopy (MRS) generally involves the summation of multiple averages to build up sufficient signal-to-noise ratio (SNR). Proper summation requires temporal stability of the averages, which is difficult to achieve due to temporal drift in the main ( $B_0$ ) magnetic field and subject motion (both physiological and bulk). If not accounted for, the resulting frequency and phase drifts give rise to incoherent signal averaging, which leads to artifactual line broadening, lineshape distortion, and reduced SNR. Here, we describe a simple new method for the estimation of frequency and phase drifts in MRS data. The proposed method, named “spectral registration”, involves the alignment of each time domain average (FID) to a reference FID (usually the first in the series) via adjustment of frequency and phase terms. Using simulated MRS data with known frequency and phase drifts, the performance of spectral registration is compared against two commonly used drift correction methods, and spectral registration is shown to outperform these existing methods, while providing advantages in terms of versatility and breadth of applicability.

**Methods.** Spectral registration involves fitting, each signal average  $S(t)$  to a reference scan  $R(t)$ , by adjusting the frequency,  $f$  (Hz), and phase,  $\phi$  (degrees), of the signal  $S(t)$ . Here, we have chosen the reference signal  $R(t)$  to be the first average in the series. This minimization operation can be expressed as:

$$\underset{f, \phi \in \mathbb{R}}{\text{minimize}} \|R(t) - G(t, f, \phi)\| \quad [1], \quad \text{where} \quad G(t, f, \phi) = S(t) \cdot e^{2\pi i \left( f t + \frac{\phi}{360} \right)} \quad [2].$$

To limit the contribution of noise, only the first 200 ms of each FID was considered in the fitting. The above minimization was implemented in MATLAB (The Mathworks, Natick, MA, USA) using the ‘nlinfit’ function. To enable fitting of complex data while avoiding complex (non-physical) parameter estimates, the vectors  $R$  and  $G$  were modified prior to minimization by concatenating their real and imaginary parts into a single real-valued vector. The performance of the spectral registration method was compared against two existing drift correction methods: the creatine fitting method (1), and the residual water method (2). Comparison was achieved by generating ten simulated proton MRS datasets (PRESS sequence, TE=80ms, 2048 points, spectral width = 2000 Hz,  $B_0 = 3$  Tesla, 128 averages) with a simulated linewidth of 6 Hz, a SNR per average of 20, and a known quantity of frequency and phase drift. The simulated datasets were drift corrected using each of the methods mentioned above, and the estimated frequency and phase drifts were compared against the actual known drifts. The simulation data were generated using an in-house MATLAB implementation of the density matrix formalism as described in (3). The SNR of each average was defined as the peak NAA amplitude divided by the standard deviation of the noise, and the amplitude of the residual water resonance was chosen to be twice that of the NAA resonance. Finally, to demonstrate the use of spectral registration *in vivo*, spectral registration was performed on a short echo-time SPECIAL (4) MRS dataset (TR/TE=3200/8.5 ms, 128 averages) that was acquired in the medial prefrontal cortex of a healthy human volunteer on a 3 Tesla MAGNETOM Trio system (Siemens, Erlangen, Germany) with a body coil transmitter and a 32-channel head receiver array coil.

**Results.** The performance of spectral registration is illustrated in Figure 1. Figures 1a and 1b show a simulated MRS dataset before and after spectral registration, respectively. Figure 1c and 1d show the actual frequency and phase errors, respectively, of the simulated dataset (black lines), as well as the estimated frequency and phase errors, respectively, as determined by the spectral registration algorithm (gray lines). Figure 2a and 2b show the frequency and phase estimation error, respectively, of the different frequency and phase estimation methods, averaged across the 10 simulated datasets. The frequency estimation errors were 0.22 Hz, 0.39 Hz, and 0.05 Hz for the creatine fitting method (CRE), the residual water method (H2O) and the spectral registration method (SR), respectively, and the corresponding phase estimation errors were 3.80 degrees, 1.21 degrees, and 0.55 degrees. Finally, figure 3 shows the averaged *in vivo* spectrum both with (black line) and without (red line) drift correction using spectral registration. The use of spectral registration results in a reduction in the full-width at half-maximum of the residual water peak from 8.2 Hz (before correction) to 5.6 Hz (after correction).

**Discussion.** The results indicate that spectral registration provides a method of accurately estimating and correcting frequency and phase drifts that occur in MRS data acquired over multiple signal averages. Not only did the spectral registration method outperform both the creatine fitting method and the residual water method in terms of both frequency and phase estimation accuracy, but it also provides advantages in terms of versatility and breadth of applicability. Specifically, spectral registration does not require the collection of navigator echoes, and it does not rely on the presence of specific resonances such as residual water or creatine. Spectral registration may perform poorly in datasets containing frequency components that are not stable from scan-to-scan, such as unstable water suppression. In such cases, the performance of spectral registration can be restored by performing the registration over a limited frequency range to exclude the unstable frequencies (results not shown).

**References.** 1. Waddell KW, et al. *Magn Reson Imaging* 2007;25(7):1032-8. 2. Helms G, et al. *Magn Reson Med* 2001;46(2):395-400. 3. Near J, et al. *NMR Biomed* 2013;26(11):1353-62. 4. Mekle R, et al. *Magn Reson Med* 2009;61(6):1279-85.

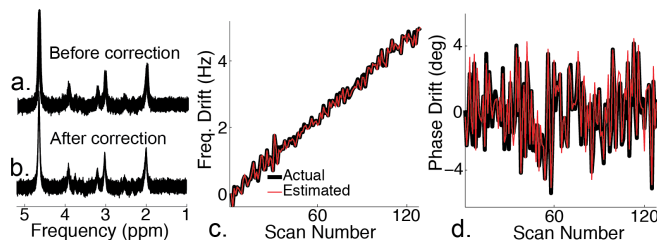


Figure 1. Plots showing the simulated data before (a) and after (b) spectral registration, and the actual vs. estimated frequency drift (c) and phase drift (d).

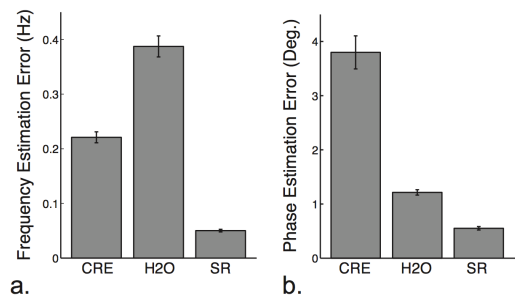


Figure 2. Frequency (a) and phase (b) drift estimation error for the creatine fitting (CRE), residual water (H2O), spectral registration (SR) methods.

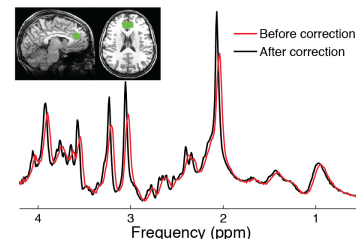


Figure 3. *In vivo* MRS data before and after spectral registration.