Field-Frequency Locked in Vivo Proton MRS on a Whole-Body Spectrometer

Pierre-Gilles Henry, Pierre-François van de Moortele, Eric Giacomini, Arno Nauerth*, Gilles Bloch

CEA, Service Hospitalier Frédéric Joliot, Orsay, France; * BRUKER Medical, Ettlingen, Germany

Introduction

The main field stability of modern supraconducting magnets normally ensures a very slow frequency drift. In spite of this, spectrometer frequency must be adjusted several times per hour during prolonged proton MRS studies, in order to maintain optimal water suppression, stable efficiency of highly selective editing pulses, or clean subtraction in difference spectroscopy. Spectrometer frequency update becomes critical when rapid main field drift occurs, because of a defect in the supraconducting coil or due to temperature variation at the level of the passive iron shims of the magnet. In this study, we demonstrate that field-frequency lock (FFL) can be achieved during localized brain proton MRS by interleaving, with the scan of interest, a small flip angle acquisition to monitor the non-localized whole head water peak as a reference signal. This approach exploits the possibility offered by modern spectrometers to process accumulating data on the flight and does not require significant modifications of the spectrometer hardware.

Materials and Methods

The FFL was implemented on a whole-body 3 T BRUKER AVANCE spectrometer for a PRESS sequence. The principle of the approach is depicted in Figure 1. During data accumulation each PRESS scan was interleaved with a small flip angle non-localized reference scan to monitor the magnet frequency drift. Using the « pipe filter » capability of BRUKER ParaVision™ software, each reference scan was processed in real time to calculate the frequency shift of the water signal and the result was used to update, with a smoothing window of 12 sec, the current delivered in the Z0 shim coil. To determine the frequency shift between the first and the n^{th} reference scans, the phase difference $\Delta\varphi(t)$ between the two reference FID's was computed for each complex time point t and the linear phase shift was estimated using a non-iterative least-squares fit of $\Delta\varphi(t)$ versus t. This approach was much faster than using an FFT, and proved to be highly accurate even on a broad water signal. To reduce the minimum available increment in the Z0 shim current adjustment, a current divider was installed on Z0 channel at the output of the shim power supply. This was the only hardware modification required to implement the FFL. To validate the proposed approach in vivo, proton MRS of the brain was performed on one of the co-authors using a BRUKER head coil. The interleaved PRESS/pulse-acquire sequence was run with a repetition time (TR) of 2 sec. To induce a rapid field drift, the passive iron shims of the magnet were heated by running the gradients with a heavy duty cycle.

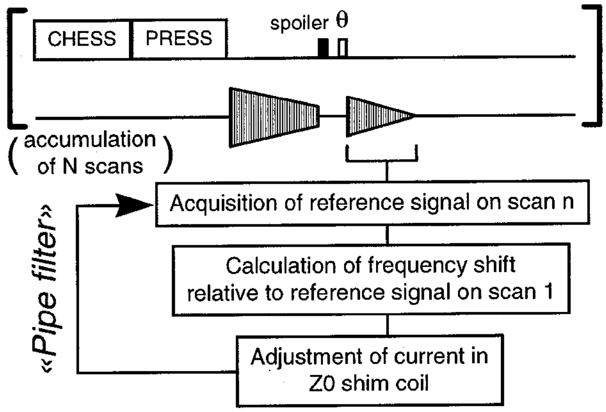

Fig. 1. Flowchart of the field-frequency lock.

Results and Discussion

Due to respiratory and cardiac motion, the frequency of the non-localized brain water signal is fluctuating on a short time scale, in addition to the long-term field drift (Fig. 2c). Because these fluctuations are time-correlated, the sampling rate of the reference frequency and the smoothing window for Z0 adjustment must be carefully optimized. Numerical simulations, phantom and in vivo experiments (not shown) clearly demonstrate that an inappropriate choice for these parameters could increase by a factor up to 2 the short-term standard deviation of the brain water frequency (SD_{bwf}), when using FFL. On the other hand, with a TR of 2 sec and a smoothing window of 12 sec (corresponding to the averaging of 6 reference frequency measurements), SD_{bwf} is only marginally affected by FFL, whatever the respiratory rate of the subject within the physiological limits (0.17 to 0.33 Hz). The in vivo performance of FFL is illustrated in Fig. 2. In these data recorded with a self-paced breathing of the subject, SD_{bwf} (calculated after subtraction of the long-term drift) increased only from 0.23 to 0.24 Hz due to FFL, while the systematic frequency drift was perfectly corrected, resulting in a narrower line width of brain metabolites.

Efficient FFL has been demonstrated for a PRESS sequence, but the same approach could be directly used for any spectroscopic technique with a TR long enough to apply the Z0 correction. In addition to the improvement in line shape, a major benefit of FFL is to stabilize the frequency on a time scale where systematic subtraction artifacts would deteriorate spectra obtained by difference (e.g. ISIS localization combined with spectral editing).

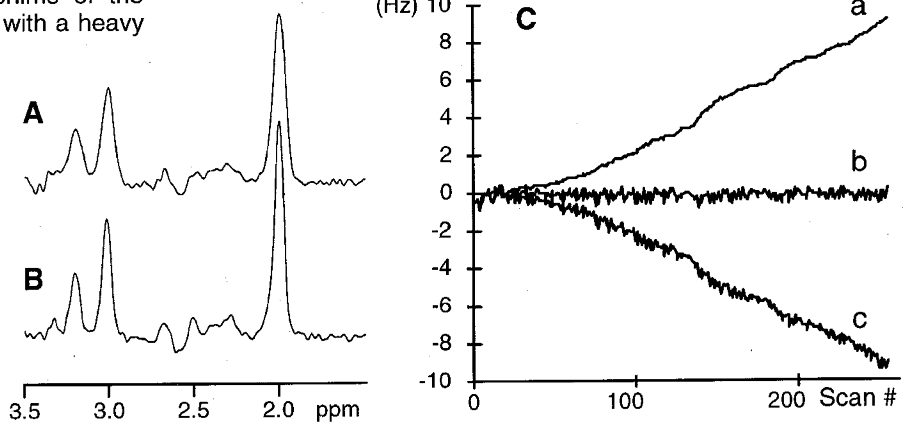

Fig. 2. In vivo spectra from the occipital lobe (15 ml, TE = 68 msec) obtained (A) without and (B) with field-frequency lock in the presence of an important field drift (≈1 Hz/min). (C) The measured reference frequencies (b) corresponding to (B) are plotted for each scan, as well as the applied Z0 corrections (a) and the calculated frequencies without correction (c), equal to (b) minus (a).