Performance analysis of the two spectroscopic imaging sequences LRE and EPSI

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Introduction: The practical value of high spatial resolution chemical shift imaging (CSI) is compromised by long total scan durations. To achieve shorter measurement times, fast pulse sequences for spectroscopic imaging (SI) can be employed at the expense of lower sensitivity relative to conventional CSI (1). Based on a gradient balanced free precession sequence Linear Response Equilibrium (LRE) has been shown to be a promising method for spectroscopic imaging with high sensitivity as coherent transverse magnetization contributes to the periodically evolving steady-state signal (2).
In LRE varying RF pulse amplitudes, modulated by a periodic flip function $\omega(t)$, allow for the design of a desired excitation profile in the frequency domain. The feasibility of LRE for fast spectroscopic imaging with simultaneous spatial and spectral encoding and an intrinsic water or fat suppression has been demonstrated previously (3). On the other hand, Echo Planar Spectroscopic Imaging (EPSI) has been widely used as it provides the same high signal-to-noise ratio per unit time (SNR_t) as classical CSI (1) and also permits simultaneous spatial and spectral encoding.
In this work, we compare the fast spectroscopic imaging sequences LRE and EPSI in terms of sensitivity. The signal of both methods was calculated numerically and compared in controlled phantom experiments.

Methods and Materials: Since two subsequent acquisition windows of the simultaneous spatial and spectral readout in LRE are separated by an RF pulse and balanced gradient waveforms, the maximum spectral bandwidth is limited by constraints dictated by the minimal repetition time (i.e. approx 500Hz on modern MR scanners). The sequence intrinsic spectral selectivity of LRE results in broad stopbands in the steady-state transverse magnetization which can be utilized for signal suppression.
For the simulations and experiments, an LRE sequences design with equally sized stop- and passbands was chosen thereby fixing the relative ratios of the different flip amplitudes to the Fourier coefficients of the excitation function. Keeping these ratios constant the entire set of flip angles was optimized to optimal SNR performance using numerical calculations. The EPSI sequence was set up to sample FID signals excited with the Ernst angle.
Simulations: In the numerical model of the LRE sequence, pulses and inter pulse delays of free precession were described by rotation matrices with exponential damping by T1 and T2 terms. The steady-state signal was calculated by solving the matrix equation for the pulse sequence with periodically varying pulse amplitude under the condition of equal magnetization vectors before and after one period of the flip function $\omega(t)$.
Equal noise statistics is assumed for both LRE and EPSI given identical spectral and readout bandwidths. Since at minimum possible TR sampling efficiency is only 30% in LRE higher readout bandwidths relative to EPSI had to be used with concurrent increase in noise. Following the definition in (1) the SNR_t was calculated as the ratio of the spectral amplitude S and the product of the standard deviation of the spectral noise and the square root of the total measurement time T_{meas}: $SNR_t = S \cdot \left(\sqrt{T_{meas}}\, \sigma_{spec} \right)^{-1}$.
Measurements: A spherical plastic phantom filled with $MnCl_2$ doped water (T1: 1015ms; T2 87 ms) and olive oil (T1: 278ms; T2: 50ms) was used for the experiments. In both LRE and EPSI a 10mm slice was measured with a resolution of 1.2mm x 1.2mm in-plane. Scans were acquired on a clinical 3T MR-system (Philips Healthcare, Best, The Netherlands) with a spectral resolution of 3.6Hz and 5Hz. In contrast to the simulations, the spectral bandwidth was not assumed to be the same in both scans but for technical reasons approximately three times larger in EPSI than in LRE. Spectral amplitudes were averaged over a rectangular region in the centre of the measured slice. The standard deviation of the spectral noise was derived from the spectrally reconstructed data of a separate noise scan without RF pulses.

Results: The ratio SNR_t(LRE)/SNR_t(EPSI) is given in Figure 1 as a measure of the sensitivities of LRE and EPSI (percent values displayed with different colors) for four sets of relaxation parameters. Equal spectral bandwidth and resolution were assumed for both sequences. The color maps reveal a small dependency on spectral resolution. The SNR_t ratio decreases with decreasing time between two acquisition windows. For short T2* times LRE shows increased SNR_t efficiency. However only at low bandwidth LRE outperforms EPSI. The influence of T1 on SNR_t remains very small. Overall, ratios between 59% and 139% can be found in the analyzed parameter region.
Comparing sensitivity values measured in olive oil and in water (figure 2 A and B) no clear trend is visible with respect to relaxation times. SNR_t for both sequences is similar in the measurements with the smaller resolution of 3.6Hz. At 5Hz EPSI performs significantly better for the set of acquisition parameters chosen.

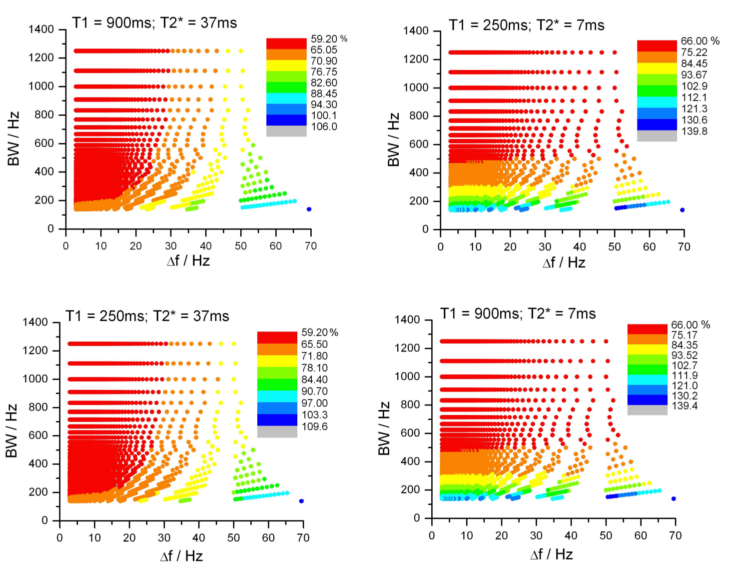

Figure 1: Simulations of the two spectroscopic image sequences LRE and EPSI at equal spectral bandwidth and spectral resolution for four sets of relaxation times. The percentaged ratio of SNR_t(LRE) / SNR_t(EPSI) is color-coded and displayed as a function of spectral bandwidth (BW) and spectral resolution Δf.

Discussion and Conclusion: Due to larger noise resulting from lower sampling efficiency the high steady state signal of LRE translates only for short transverse relaxation times and low spectral bandwidth into an advantage of LRE over EPSI in terms of sensitivity. The sequence intrinsic suppression of periodic spectral bands in LRE can be used to reduce the spectral field-of-view and thus the spectral bandwidth which, in turn, improves the SNR_t performance of LRE. This situation was assumed for the measurements where a three times lower spectral bandwidth was used in LRE compared to EPSI. Despite this setting our experimental data do not show a significantly better sensitivity for LRE relative to EPSI. At 5Hz spectral resolution significant higher SNR_t of EPSI was seen in the experiments. This may be attributed to longer excitation pulses in EPSI that result in more homogeneous excitation of the slice. Also differences in eddy current effects may play a role in the experimental data.

References: (1) R Pohmann et al., J Magn Reson 129:145 (1997);
(2) KW Eberhardt et al., J Magn Reson 178:142 (2006);
(3) KW Eberhardt, et al., Proc. Intl. Soc. Mag. Reson. Med. 14; (2006)

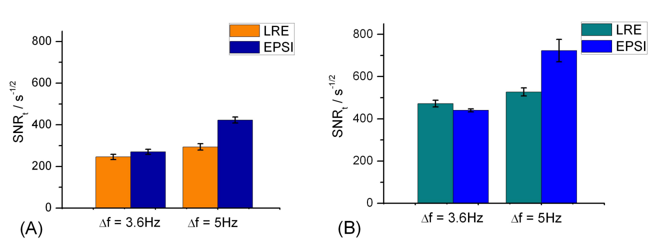

Figure 2: Measured data of SNR per unit time in a phantom for two different spectral resolutions for LRE and EPSI. (A) olive oil; (B) water.