Frequency Off-Resonance Effects on Parametric SSFP Imaging

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Introduction: Due to advances in hardware, fully balanced steady-state free precession (SSFP) techniques have gained renewed attention for fast imaging with good tissue contrast and high spatial resolution. Recently, parametric SSFP methods have been used to generate MR-dependent tissue parameters such as *T1* and *T2* [1,2,3]. In [4], it was shown that a "variable flip angle" radial steady-state free precession (RAD-SSFP) method with slice profile correction can be used for the direct and fast estimation of the *T1/T2* ratio. This ratio can be used for tissue characterization. The advantage of this technique is that a *T1/T2* map can be obtained from data acquired in a very short period of time (~3-4 s per slice) which makes the technique attractive for tissue characterization in regions of the body where fast imaging is needed. In this work, we analyze the effect of field inhomogeneities on the estimation of *T1/T2*.

Theory: The steady-state equation of SSFP with an alternating-phase excitation pulse train [5] is indicated in Eq. (1), where α is the flip angle,

$$\left\{\begin{array}{l} M=\sqrt{M_x^2+M_y^2} \\ M_x=QE_2\sin\alpha\sin(\beta+\pi) \qquad\qquad M_y=Q\sin\alpha(1-E_2\cos(\beta+\pi)) \\ Q=\dfrac{M_0(1-E_1)}{(1-E_1\cos\alpha)(1-E_2\cos(\beta+\pi))-(E_1-\cos\alpha)(E_2-\cos(\beta+\pi))E_2} \end{array}\right\} \quad (1)$$

$$M=\frac{M_0(1-E_1)\sin\alpha}{1-E_1E_2-(E_1-E_2)\cos\alpha}\approx\frac{M_0\sin\alpha}{T_1/T_2\,(1-\cos\alpha)+(1+\cos\alpha)} \quad (2)$$

$E_1=e^{-TR/T_1}$ and $E_2=e^{-TR/T_2}$, $\beta=\gamma\cdot\Delta B\cdot TR$ is the frequency offset with ΔB representing the field inhomogeneity. In SSFP, *TR* and *TE* << *T1* and *T2*, thus $e^{-TR/T1}\approx 1-TR/T1$ and $e^{-TR/T2}\approx 1-TR/T2$.

When the magnetic field inhomogeneity can be neglected, $M_x = 0$ and Eq. (1) can be simplified to Eq. (2). This is the form of the steady-state equation that is commonly found in the literature and used for parameter estimation from SSFP data. For instance, for SSFP data acquired with a variable flip angle, α, the signal intensity can be fitted to Eq. (2) to estimate the *T1/T2* ratio. Equation (2) is valid only under the assumption that the magnetic field inhomogeneity is small.

Methods: To evaluate the effect of magnetic field inhomogeneities on the estimation of *T1/T2*, numerical simulations were performed. Using Eq. (1) and known ("true") *T1/T2* values, variable flip angle data (i.e., $M(\alpha)$) were generated at different frequency offsets. These data points were fitted to Eq. (2) to generate the "estimated" *T1/T2* values. Experiments were also performed with Nickel-doped agarose phantoms. In the phantoms we measured *T1* and *T2* using conventional inversion recovery and SE methods, respectively. These values were used to determine the "true" *T1/T2*. Data were acquired with the variable flip angle RAD-SSFP method proposed in [4]. To generate data at various frequency offsets, the carrier frequency was manually shifted. Then the *T1/T2* values were estimated from a variant of Eq. (2) which included compensation for the non-ideal slice profile of the excitation pulse [4].

Results and Discussion: The results of the numerical simulations are shown in Fig. 1. In this figure, plots of the "estimated" *T1/T2* vs. the frequency offset are shown for various "true" *T1/T2* values (indicated by the number above each line). From this figure, it can be observed that the frequency offset affects the *T1/T2* estimates. In general, the effect is more pronounced for larger *T1/T2* values. The results for phantoms with "true" *T1/T2* values of 8.19 and 21.03 are shown in Fig. 2 with the data fitted to a polynomial. As predicted in the numerical simulations, the frequency offset influences the *T1/T2* estimation, and the effect is more pronounced for the larger *T1/T2* values.

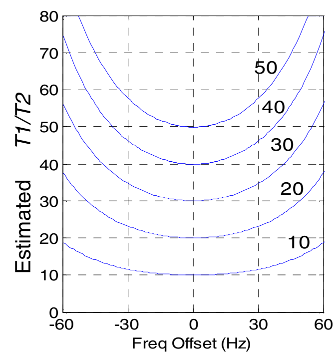

Fig. 1. Simulations of *T1/T2* estimates vs. frequency offset. Number above each line is the true *T1/T2*. The minimum of each curve corresponds to the true *T1/T2* value.

In state-of-the-art scanners the field inhomogeneity caused by irregularities of the main magnetic field is generally very small and in most SSFP studies the effect of frequency offset is neglected. Tissue susceptibility, however, can cause significant frequency offsets and this introduces errors in the estimation of parameters from SSFP such as *T1*, *T2* or *T1/T2*. A solution to achieve more accurate estimates is to scan the object at a few frequency offsets and use the minimum point (or the minimum of the fitted curve) as the final estimate.

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References: [1] Griswold MA, ISMRM, 12, 2661 (2004). [2] Newbould R, ISMRM, 13, 99 (2005). [3] Newbould R, ISMRM, 13, 2191 (2005). [4] Li Z, ISMRM, 13, 2383 (2005). [5] Haacke EM, Wiley-Liss, 1999.

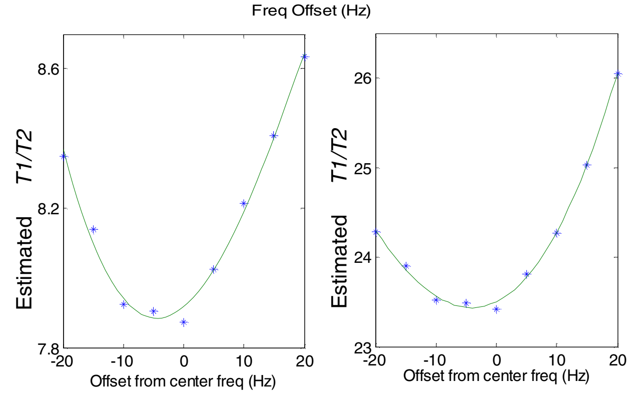

Fig. 2. *T1/T2* estimates vs. frequency offset for phantom data.