Transverse Relaxation Time (T2) and Susceptibility Measurement with Phase-Cycled Steady-State Free Precession

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Introduction: Driven equilibrium, single pulse observation of T_2 (DESPOT2) allows for rapid transverse relaxation time measurement from a series of fully-balanced steady-state free precession (SSF) images acquired with constant repetition time (TR) and varied flip angle (α)[1]. A limitation of the technique, however, is the sensitivity of the SSFP signal to off-resonance effects, which increase with field strength and present as bands of artificially reduced signal repeating at frequencies of 1/TR. Two effective strategies for reducing the appearance of these bands is to (i) minimize TR and (ii) varying the phase of the radio-frequency (RF) pulses, which shifts the spatial location of the bands. In previous work[2], we proposed the acquisition of two DESPOT2 data-sets with differing RF phase increments. From these data, two T_2 maps could be calculated and combined to yield an artifact-free map. Unfortunately, while this approach performed well at 1.5 Telsa (T), it was less effective at higher field (3T) or with long TR (associated with high spatial resolution or low receiver bandwidths). Here we present a more general form of the phase-cycling approach which accounts more fully for the precession of the transverse magnetization over the TR interval and demonstrate the efficacy of the approach i*n vivo* at 3T.

Methods: The general expressions for the x and y components of the steady-state magnetization are given by

$M_x = \rho(1-E_1)E_2 \sin\alpha \sin\beta / d$ [1], $M_y = \rho(1-E_1)E_2 \sin\alpha(\beta - E_2)/d$ [2],

$d = (1-E_1\cos\alpha)(1-E_2\cos\beta) - E_2(E_1-\cos\alpha)(E_2-\cos\beta)$ [3], with the associated measured signal, $S_{SSFP} = (M_x^2+M_y^2)^{1/2}$ [4].

Here, E_1=exp(-TR/T_1), E_2=exp(-TR/T_2) and ρ is proportional to the proton density. β is the precession angle of the transverse magnetization over the TR interval which we can consider a summation of the phase increment of the RF pulses, ϕ plus an additional off-resonance term equal to the resonant frequency, ω, multiplied by TR, $\beta=\phi+\omega TR$. In our prior approach[2], ωTR was generally assumed to be 0 except immediately adjacent to air-tissue interfaces. At higher field strength, however, susceptibility effects increase and impinge further away from interfaces. Here $\omega TR \neq 0$, and in order to extract meaningful T_2 values, it is necessary to fully model the SSFP signal through a three-parameter non-linear fit for ρ, T_2 *and* ω to multi-angle and multi- SSFP data.

To demonstrate the efficacy of the approach, 3D SSFP data were acquired at 3T of a homogeneous, nickel chloride doped water phantom, as well as of a whole brain using the parameters: 22cm^2 x 16cm field of view, 220x220x160 matrix, *TE / TR* = 3.6ms / 7.2ms, bandwidth = ±31.25kHz, α = 15° and 65°, ϕ = 0 and π. Since DESPOT2 requires *a priori* knowledge of T_1, a matched T_1 map was calculated from multi-angle spoiled gradient recalled echo (SPGR) imaging data using the DESPOT1 method[3]. To account for flip angle variations resulting from B_1 field inhomogeneity, the DESPOT1-HIFI approach, involving the additional acquisition of an inversion-prepared SPGR image[4], was used to calibrate the B_1 field. DESPOT1 and DESPOT1-HIFI data were acquired with the following parameters. For SPGR: *TE / TR* = 1.1ms / 6ms, bandwidth = ±17.8kHz, α = 4° and 18°. For IR-SPGR: *TE / TR / TI* = 1.1ms / 6ms / 450ms, bandwidth = ±17.8kHz, α = 5°. Total imaging time for all data was approximately 20 minutes.

From the SSFP data, two phantom and whole-brain T_2 maps were calculated; the first using the previous described approach in which T_2 maps are calculated from the flip angles acquired with identical ϕ. These two maps are then combined using maximum intensity projection (MIP) to yield the final MIP T_2 map. The second T_2 map was calculated using a non-linear fit of Eqn. [4] to the SSFP data for ρ, T_2 and ω using the Levenberg-Marquardt least-squares approach.

Results: Figures 1 and 2 show the slices through the raw SSFP data, as well as calculated T_2 and ω maps, for the water-filled sphere and human brain data, respectively. Obvious improvement is noted in the 3-parameter fit T_2 maps, compared with the MIP T_2 maps, for both the sphere and brain data. Examination of the calculated frequency maps clearly demonstrates the inappropriateness of the ωTR=0 assumption made in the MIP approach throughout most of the image volume. Further, the 3-parameter estimates show strong agreement with reference multi-TE spin-echo T_2 measurements (*not shown*), with less than 5% absolute difference.

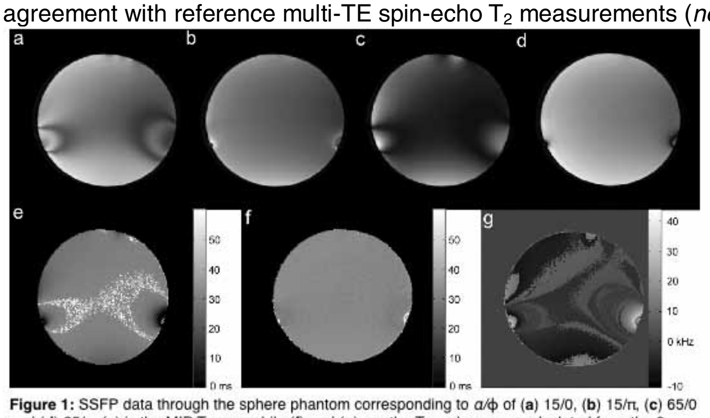

Figure 1: SSFP data through the sphere phantom corresponding to α/ϕ of (**a**) 15/0, (**b**) 15/π, (**c**) 65/0 and (**d**) 65/π. (**e**) is the MIP T_2 map while (**f**) and (**g**) are the T_2 and ω maps calculated from the 3-parameter non-linear fit.

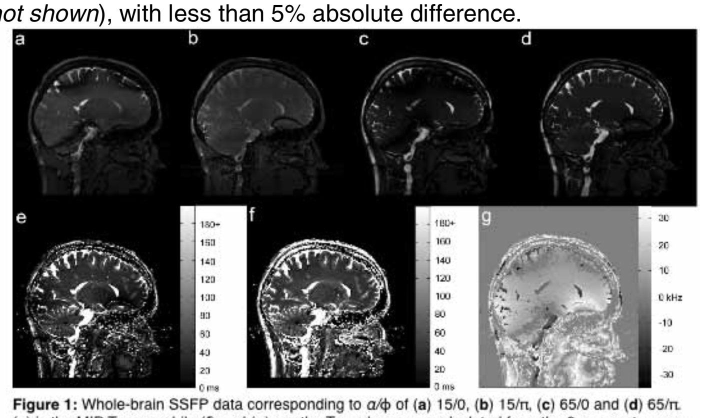

Figure 1: Whole-brain SSFP data corresponding to α/ϕ of (**a**) 15/0, (**b**) 15/π, (**c**) 65/0 and (**d**) 65/π. (**e**) is the MIP T_2 map while (**f**) and (**g**) are the T_2 and ω maps calculated from the 3-parameter non-linear fit.

Discussion / Conclusion: Here we have presented a general approach for dealing with off-resonance effects in the DESPOT2 T_2 mapping method which accounts more fully for precession of the transverse magnetization during the TR period. The approach provides for near artifact-free T_2 maps without adding to acquisition time compared with the previous MIP approach.

References: [1] Deoni SCL et al. MRM,2003;49:515-526, [2] Deoni SCL et al. MRM,2004;52:435-439, [3] Christensen KA et al. J Chem Phys. 1974;78:1971-1977, [4] Deoni SCL. 2007 ISMRM abstract #306.