Fast T2 Mapping Using Partially Spoiled Steady State Free Precession (T2-pSSFP)

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Introduction. Only recently, an analytic solution for partial spoiling of the steady state of gradient echo sequences (pSSFP) was presented [1]. Radio-frequency phase cycling (RF spoiling) refers to a linear increment in the differential RF phase of consecutive excitation pulses $\phi_k - \phi_{k-1} = k\phi$, characterized by the phase shift increment ϕ. The steady state depends sensitively on ϕ, yielding SSFP-FID (FISP, FFE, …) for $\phi = 0°$ and SPGR (FLASH, T1-FFE, …) for ϕ=50° or 117°. It was been shown that for small TR and ϕ, the width of the transition from SSFP-FID to SPGR is inversely proportional to T2. Here, we make use of the approximate solution for partially spoiled SSFP sequences for small ϕ, to allow for fast 3D quantitative T2 mapping.

Theory. In [1] an analytical description of SSFP with RF spoiling is given. For small ϕ, the solution to the steady-state signal can be derived, which simplifies for $T_1/T_2 >> 0.5(1+\cos\alpha)/(1-\cos\alpha)$ to yield:

$$S_\phi(\alpha, TR, T_{1,2}) \approx \frac{\sin\alpha}{1-\cos\alpha} \cdot \frac{1}{\sqrt{\lambda^2+\phi^2}} \cdot \frac{\delta}{\xi} \quad \text{with} \quad \lambda := \frac{2}{\xi} \cdot \frac{TR}{T_2} \qquad [1]$$

where δ:=TR/T_1 and the quantity ξ depends on the flip angle α and must be determined numerically and typical values are given in [1]. The quotient of two acquisitions with different partial RF spoiling increments (ϕ_1, ϕ_2) is thus given by

$$f^2(TR, T_2, \alpha, \phi_{1,2}) = \frac{S^2_{\phi 1}(\alpha, TR, T_{1,2})}{S^2_{\phi 2}(\alpha, TR, T_{1,2})} = \frac{\lambda^2+\phi_2^2}{\lambda^2+\phi_1^2} \qquad [2]$$

and is a function of α, TR and T2 only. From Eq. [2], T2 can be derived yielding

$$T_2(\phi_{1,2}, TR, \alpha) = \frac{2TR}{\xi} \cdot \sqrt{\frac{S^2_{\phi 1} - S^2_{\phi 2}}{S^2_{\phi 2}\cdot\phi_2^2 - S^2_{\phi 1}\cdot\phi_1^2}} \qquad [3]$$

Eq. [3] is assumed to yield accurate results for $T_1/T_2 >> 0.5(1+\cos\alpha)/(1-\cos\alpha)$. For tissues, $T_1/T_2 \sim 10$ and thus constraining $\alpha >> 25°$ (for CSF $T_1/T_2 \sim 2$, constraining $\alpha >>$ 55-60°).

Methods. An SSFP-FID sequence allowing for partial spoiling increments ϕ between 0° and 360° was tested on a 1.5T clinical scanner (Siemens Espree) for fast generation of T2 maps. The protocol was setup in 3D with 1.3mm isotropic resolution (imaging matrix: 192x192x144) using hard pulse excitations of 1ms duration. The flip angle was set to 70°. The bandwidth was set to 240Hz/Pixel yielding a TR of 5.4ms and four averages were taken. The 3D T2 scan was completed within 5 minutes. The flow sensitivity of SSFP-FID (with $\phi = 0°$) is reduced using $\phi > 0°$ and therefore partial spoiling increments of 1° and 10° were used, respectively.

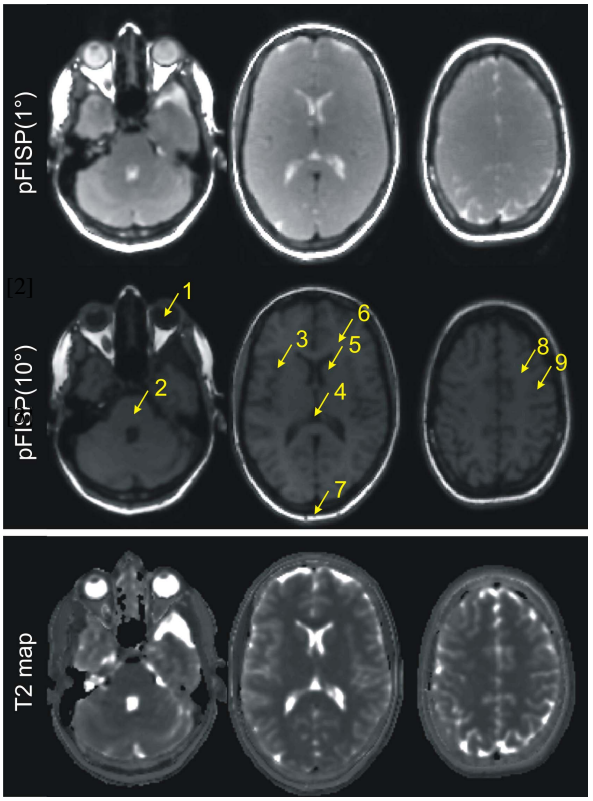

Fig. 1: Fast T2 mapping using T2-pSSFP with α=70°. Axial samples images of pSSFP using ϕ=1° (top row) and 10° (middle row) and with corresponding derived T2 map using Eq. [3] (bottom row). The found T2 values for regions of interest (ROI) as indicated by the yellow arrows can be found in the results section.

Results & Discussion. For illustrative purposes a 3D scan of human brain was performed on a healthy volunteer and is shown in Fig. 1. For low partial spoiling ($\phi \sim 0°$), gray and white matter show similar contrast as can be expected from common, i.e. non RF-spoiled, SSFP-FID (Fig. 1, top row). Further increase in the phase shift (ϕ) increment results in stronger signal attenuation for tissues with increased T2 as reflected in the observed signal contrast between CSF, gray and white matter (Fig. 1, middle row). From this, Using Eq. [3], a quantitative T2 map can be derived as displayed in Fig. 1 (bottom row). The derived T2 values for selected regions of interest (ROI, as indicated in Fig. 1, middle row) are in good agreement with literature: (1) Eye: 1140±120ms, (2) brain stem: 64±2ms, (3,9) gray matter: 95±7ms, (4) CSF: 810±290ms, (5,8) white matter: 61±2ms, (6) caudate nucleus head: 77±4ms, (7) fat: 88±5ms. For tissues, T2-pSSFP yields accurate results (α=70°>>25°), but underestimates T2 for CSF (α=70°>>55-60°). In contrast to conventional T2 mapping techniques using 2D multi-echo spin echo sequences, T2-pSSFP allows 3D isotropic mapping, or in contrast to other SSFP based T2 mapping techniques, such as DESPOT2 [2], does not rely on T1. In addition, T2-pSSFP is based on two identical acquisitions with respect to TR, α, gradient strength, etc… and thus does not suffer from diffusion, magnetization transfer or other sequence related signal ambiguities. The validity and accuracy of this new T2-mapping technique will be analyzed as a function of flip angles for different targets, especially for use with optimal flip angles (yielding maximal signal and thus SNR).

Conclusion. We have introduced a new and fast T2 mapping technique that is based on two partially spoiled steady state free precession acquisition (T2-pSSFP). The T2 mapping technique seems to yield accurate results for tissues exhibiting considerable differences in T2 and T1 (T1/T2 >> 1), whereas for substances with highly similar T_1 and T_2 ($T_1/T_2 \sim 1$), i.e. CSF or tissues in the presence of considerable amounts of contrast agents, T2 is underestimated.

References. [1] Ganter C, MRM 55 (2006). [2] Deoni et al, MRM 49 (2003).