Introduction. The width of transition of steady-state free precession (SSFP) to RF-spoiled SSFP is inversely proportional to the transverse relaxation time $T_2$ (1), which has been used to derive quantitative $T_2$ maps from two partially spoiled SSFPFID signals (T2-pSSFP) (2). Signal analysis based on an approximate solution being independent on the longitudinal relaxation time $T_1$, but with sensitivity to the partial spoiling increment ($\phi$), the flip angle ($\alpha$), the repetition time (TR) and to $T_2$. This approximation is valid for tissues with $T_1/T_2 >> 1$, estimation of $T_2$ was shown to be accurate whereas for liquids or for smaller flip angles, $T_2$ is underestimated. In this work, we abandon the constraint formulated in Eq. [1] and solve the more complex signal equation as given by C. Ganter in Eq. [35] (1),

$$m_\phi(\phi) = \frac{[\sigma_\phi^2 + \xi_\phi^2]^2}{\sigma_\phi^2 + \xi_\phi^2 - \eta_\phi^2}$$  \[2\]

that depends now on $T_1$, as well. We will show that an analytic expression to Eq. [2] can be found that can be used to assess $T_2$ using T2-pSSFP in combination with $T_1$ measurements.

Theory. Suppose we know $\lambda=T_2/T_1$. Eq. [2] leads to a cubic equation of form $z^3 + a_2 z^2 + a_1 z + a_0 = 0$, where $z := TR/T_2$. Thus $z = s_+ + s_- a_2 = 3$, where $s_+ = \left[r + \left(r^2 - r^2\right)^{1/2}\right]^3$ and $q := a_1/3 + a_1/9$, $r := (a_2 - a_3)/6 - \alpha^2/27$ with

$$a_0 = (1 - S_E)^{-1}(b_2 c_2 - S_R J c_2^2)$$

$$a_1 = (1 - S_R)^{-1}(2b_2 c_2 + c_2^2 - S_R(2b_2 c_2 + c_2^2))$$

$$a_2 = (1 - S_R)^{-1}(b_2 + 2c_2 - S_R(b_2 + 2c_2))$$

and definitions

$$b_2 := \xi_\phi^2 \eta_\phi^2 / \left[1 + \eta_\phi^2\right], c_2 := b_2 / \nu, \nu := \left[1 + \eta_\phi^2\right]/\left(1 - \cos \phi\right)$$

The quantity $\xi_\phi$ depends on $\alpha$ and is determined via a continued fraction expansion (see Eq. [34] in Ref. (1)) and $S_R = S(t)/S(t)$ refers to the measured quadratic signal ratio with partial spoiling increments $\phi_1$ and $\phi_2$, respectively.

Materials & Methods. All simulations, data analysis and visualizations were done using Matlab 2007b. Human brain scans were performed in 3D at 1.5T with 1.33mm isotropic visualization were done using Matlab 2007b. Human brain scans were performed in 3D at 1.5T with 1.33mm isotropic matrix size and FOV. The TR was set to 5.4ms and a hard RF pulse of 600\mu s duration was used. Partial spoiling increments were 1° and 9° and $T_1$ information was acquired using DESPOT1 ($\text{TR} = 15\text{ms}$ with $\alpha_\phi = 4\degree, 23\degree$) with essentially identical matrix size and FOV.

Results & Discussion. Using the full analytic signal description of partially spoiled SSFP, the accuracy in the estimation of $T_2$ from Eqs. [3-5] can be analyzed as a function of $\alpha$ and $\lambda$ (Table 1). Deviation in $T_2$ is typically less than 10% for tissues ($T_1/T_2 \sim 0.1$) down to $\alpha \sim 30\degree$ provided $T_2$ is known. As expected, sensitivity on $T_1$ is low for large flip angles ($\alpha > 70\degree$), but $T_1$ information becomes increasingly important with decreasing $\alpha$, as indicated by the parameter $\delta$ in Table 1. For evaluation, in-vivo 3D T2-pSSFP brain scans were performed on a healthy volunteer and results are shown in Fig. 1. As expected, sensitivity on $T_1$ is reduced upon $T_2$ correction, but breaks down for low flip angles ($\alpha \sim 30\degree$). Observed residual $T_2$ modulations between $\alpha = 30\degree-70\degree$ are most likely due to $B_0$ field inhomogeneities which become increasingly important with lower $\alpha$, or due to inconsistencies between derived $T_2$ values from DESPOT1 and true $T_2$ values (an underestimation in $T_1$ results in an underestimation of $T_2$) which become less and less important with increasing flip angles.

Conclusion. Provided that $T_1$ is known, the constraint on high flip angles for the assessment of $T_2$ values using T2-pSSFP can be abandoned and accurate $T_2$ values can be derived with flip angles down to 30°. This offers the possibility for acquisitions with higher SNR, but requires guessed or additional measured $T_1$ values.