The influence of finite long pulse correction on DESPOT2

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Introduction

The DESPOT2 method is capable of acquiring T_2 maps within clinical acceptable acquisition times (1). This method is based on two balanced steady-state free precession (bSSFP) acquisitions while assuming instantaneous RF pulses for the calculation of T_2. However, this is a pure theoretical assumption and in practice this cannot be achieved, nor does the RF pulse duration always approach the assumption. Explicitly in the case where one would like to reduce the influence of magnetization transfer (MT) effects, one uses long RF pulses. Therefore, we propose the implementation of a correction compensating for the error introduced by the assumption of instantaneous RF pulses as introduced by Bieri and Scheffler in (2). By the implementation of this correction factor, the deviation of the acquired T_2 is independent on the pulse duration. The longer the RF pulses (relative to TR: T_{RF}/TR), the larger the deviation of the original DESPOT2 method and therefore the more important the correction described.

Theory

For the correction of finite pulses, one takes the repetition time (TR) as defined by instantaneous pulses and subtracts that part of the effective RF pulse duration (T_{RFE}, Fig. 1):

$$T_{RFE} := \begin{cases} T_{RF} & : \text{hard pulses} \\ 1.20\cdot\dfrac{T_{RF}}{TBW} & : \text{Gaussian pulses} \end{cases}, \text{ where } \zeta \approx 0.68 - 0.125\left(1+\frac{T_{RFE}}{TR}\right)\frac{T_2}{T_1} \qquad [1]$$

with TBW being the time-bandwidth product. By implementation of this correction in the DESPOT2 equation, T_2 becomes:

$$T_2 = -\left(TR - 0.68\cdot T_{RFE}\right)\Big/\left(\ln\left(\frac{m-E_1}{m\cdot E_1 - 1}\right) + 0.125\left(1+\frac{T_{RFE}}{TR}\right)\frac{1}{T_1}T_{RFE}\right) \qquad [2]$$

which is the corrected DESPOT2 equation, with $m = \left(S_2/\sin(\alpha_2) - S_1/\sin(\alpha_1)\right)\big/\left(S_2/\tan(\alpha_2) - S_1/\tan(\alpha_1)\right)$ and $E_1 = e^{(-TR/T_1)}$. When T_{RFE} is set to zero equation [2] equals the original DESPOT2.

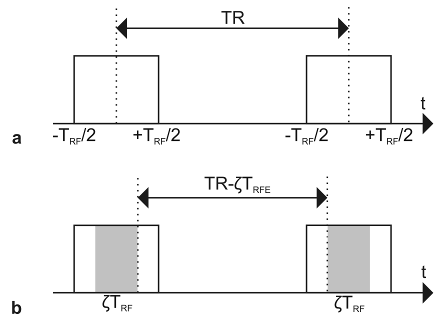

Figure 1 Definition of TR assuming instantaneous RF pulses (a) and assuming finite pulses by the use of correction factor ζ (b).

Methods

Simulations Finite difference Bloch simulations are performed for T_{RF}/TR ranging from 0.01 to 0.99, TR = 10ms, $\alpha_{1,2}$ = 15°, 55° to acquire theoretical steady-state signal intensities (after 500 iterations) for both white and gray matter (T_1/T_2 = 600ms/75ms and 1000ms/100ms respectively). From the simulations, T_2 values are calculated using equation [2] for instantaneous and finite RF pulses. All simulations and calculations are performed using Matlab R2007b (The MathWorks Inc., USA).

Measurements Measurements on a healthy volunteer are performed on a 1.5 T Espree whole body scanner (Siemens Healthcare, Germany). Two RF spoiled gradient echo acquisitions (TR = 9.8 ms, TE = 4.3 ms, $\alpha_{1,2}$ = 4°, 15°, FOV = 256x256x192 mm^3, and voxelsize = 1.33x1.33x1.33 mm^3) are performed and used to calculate T_1 by using the DESPOT1 method (1). A series of two bSSFP acquisitions (TR = 8 ms, TE = TR/2, $\alpha_{1,2}$ = 15°, 55° , FOV = 256x256x192 mm^3, and voxelsize = 1.33x1.33x1.33 mm^3) with various T_{RF} settings (a built in delay in the sequence preserves constant TR) ranging from 520 to 4800 μs (which corresponds to a T_{RF}/TR range of 0.065 to 0.6). These acquisitions are used to perform the original DESPOT2 and corrected DESPOT2 T_2 calculations. ROIs are drawn in a 15° RF spoiled gradient echo image to acquire results from gray and white matter.

Results

Simulations T_2 calculations from finite difference Bloch simulations show deviations in the calculated T_2 without T_{RF} correction: longer pulse durations result in larger deviations. The corrected DESPOT2 method shows almost no deviations (see Figure 2) and thus no dependency on the RF pulse duration.

Measurements The results of the corrected DESPOT2 method show only marginal dependency on T_{RF}/TR and thus on T_{RF} while the DESPOT2 method without correction shows large dependency on T_{RF}/TR (see Figure 4) and thus on T_{RF}. This is observed in both the gray and the white matter regions. The shown data are from the manually drawn ROIs as indicated in Figure 3. The measurement results conform to the simulation results for gray and white matter.

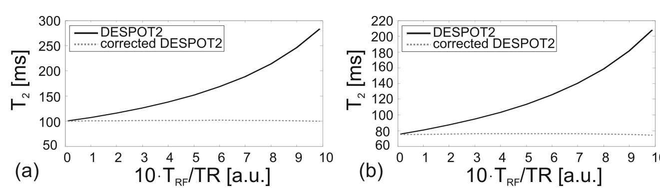

Figure 3 T_2 values calculated from the Bloch simulation signal intensities for gray matter (a) und white matter (b).

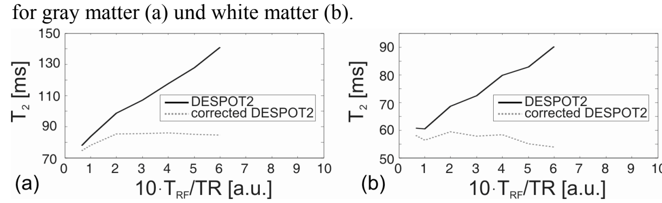

Figure 2 T_2 values calculated for gray matter (a) and white matter (b) from the measurement data.

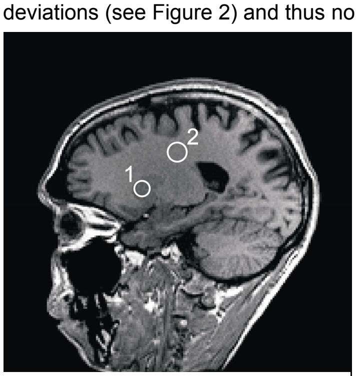

Figure 4 ROI definitions in gray (1) and white matter (2) in a 15° RF spoiled gradient echo image.

Discussion/Conclusion

The implementation of the correction for finite pulses within the original DESPOT2 method makes it independent on the RF pulse duration, and the implementation neither elongates scan time nor calculation time. T_2 values obtained for white and gray matter (T_1/T_2 = 1000/100 ms and 600/75 ms respectively) by simulations for long pulses (2 ms) with minimal TR setting (5 to 6 ms) resulted in T_2 = 130 ms and T_2 = 97 ms using the original DESPOT2 method, and T_2 = 101 ms and T_2 = 76 ms using the corrected DESPOT2 method. This is an overestimation by 30% for the original DESPOT2 and only by 1% for the corrected DESPOT2. Therefore, especially in the case one would like to use long RF pulse durations in order to reduce the influence of MT effects, it is advised to use this corrected DESPOT2 method to acquire T_2 maps independent on T_{RF} resulting in similar results as the original DESPOT2 method with short RF pulses.

References

(1) Deoni et al. MRM 52:435-439 (2004); (2) Bieri et al. MRM 62: 1232-1241 (2009)