Correction of slice profile deformations and estimation of optimal flip angles to enable accurate T_1/T_2 mapping using 2D variable flip angle techniques

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INTRODUCTION Quantitative MR is in the research spotlight for non-invasive tissue characterization using parametric mapping of T_1 and T_2. Rapid and accurate T_1 and T_2 quantification techniques using variable flip angles (VFA), such as DESPOT1/2, have been proposed [1] for the brain. DESPOT1/2 comprises (i) 3D RF-spoiled fast low angle shot (FLASH) acquisitions for T_1 quantification and (ii) 3D balanced steady state free precession (b-SSFP) acquisitions for T_2 quantification, each including at least two acquisitions using different flip angles [1]. For 2D acquisitions, short repetition times (TR) evoke T_1 and flip angle dependent saturation phenomena that deform the slice profile [2,3] and hence bear the potential to deem T_1 and T_2 quantification inaccurate. Therefore this study examines the impact of slice profile deformations on 2D T_1 and T_2 quantification using VFA in simulations and phantoms. To tackle the detrimental effects of slice deformation, a correction approach is proposed that enables accurate quantification of T_1 and T_2. Furthermore, we propose a new method for deriving optimum flip angles for 2D DESPOT1/2 to enhance the accuracy of parametric mapping. The applicability of this approach is demonstrated in phantom and in vivo studies.

METHODS Flip angle dependent signal intensities were calculated in the steady state using Bloch simulations and compared with experimental data derived from a 3.0 T MR scanner (Siemens Verio, Siemens Healthcare, Erlangen, Germany). For this purpose an oil phantom was used with values of T_1=200ms and T_2=145ms determined with standard IR and SE sequences. B_1-homogeneity was verified using the PhiFA CUP approach [4]. The impact of the signal change on the quantification of T_1 and T_2 using two flip angles of the uncorrected VFA approach were calculated. Using original rf-pulse shapes in Bloch simulations of the slice profile, we sought to correct for the discrepancies between theoretical and measured signal. Furthermore, we used three flip angles for parameter quantification to achieve better stability, where one flip angle corresponded to the maximum signal. To determine the optimum flip angle set considering noise contributions, simulations were performed. Eight sets of possible extreme noise configurations were simulated (signal+noise and signal-noise for all flip angles) and the standard deviations were calculated for all possible combinations and compared to the measurement. T_1 and T_2 quantification were conducted in the phantom and in vivo with flip angle sets causing minimal errors. Brain images were obtained (FLASH and b-SSFP, TE/TR=2.5ms/5ms, voxel size (0.8x0.8x8) mm³, 32 channel receive head coil) with optimal flip angles for DESPOT1/2 and for the corrected approach and T_1 and T_2 maps were calculated. The T_1 map resulting from each approach was used as a basis for the T_2 quantification. B_1 correction was accomplished using relative B1-Mapping with the standard "rf-map" routine on the scanner.

RESULTS Figure 1 illustrates the discrepancy between the theoretical, the measured, and the slice profile corrected signal intensity. The corrected data using Bloch simulations revealed good agreement with the measured signal intensities for FLASH and b-SSFP. The flip angle resulting in maximum signal was found to be 23° for FLASH and 103° for SSFP, which does not correspond to the theoretical Ernst angles (FLASH=13°, SSFP=81°). The minimum error of 4.6% occurred for a set of 7°/*23*°/87° for T_1 quantification (Fig. 2a) while an error of 4.8% occurred for a set of 60°/*103*°/151° for T_2 quantification (Fig. 2b). Figure 3 and 4 shows T_1 and T_2 maps obtained from the oil phantom and from the brain of a healthy volunteer. DESPOT1/2 underestimated T_1 and T_2 in the phantom by 63% resp. 47%. The corrected VFA approach agreed well with the phantom's T_1,T_2 (-1%,+3%). *In vivo* DESPOT1/2 yielded T_1/T_2 of 378±17ms/22±2ms for white matter and T_1/T_2 of 537±22ms/34±5ms for gray matter. The corrected approach revealed T_1/T_2 of 1140±90ms/63±3ms for white matter and T_1/T_2 of 1770±90ms/99±19ms for gray matter, which is in the range of T_1 and T_2 values reported in the literature [5].

DISCUSSION AND CONCLUSIONS Our results demonstrate severe T_1,T_2 quantification errors due to slice profile deformations in fast 2D VFA acquisitions. The proposed correction method based on Bloch simulations render the 2D VFA quantification of T_1 and T_2 accurate. The evaluation method calculating optimum flip angles to mitigate errors caused by noise could be resembled by measurements. Parameter mapping in vivo using slice profile simulations may remain challenging when partial volume effects have to be considered. SNR constraints of DESPOT 1/2 remain a concern for accurate tissue characterization using parametric mapping of relaxation times. This suggests that the traits of dedicated surface coil arrays targeting the anatomy of interest will be beneficial to provide further SNR improvements. While this work focuses on brain imaging we anticipate to extend our explorations into myocardial tissue characterization.

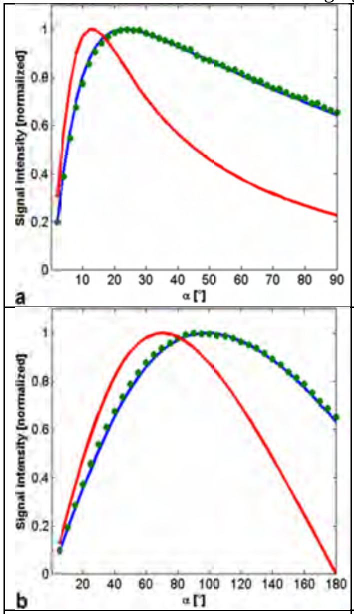

Figure 1: Theoretical (red line) vs. measured (green dots) vs. simulated slice profile corrected signal intensities (blue line) for FLASH (a) and b-SSFP (b) over different flip angles. The corrected signal intensities agree very well with the measurement.

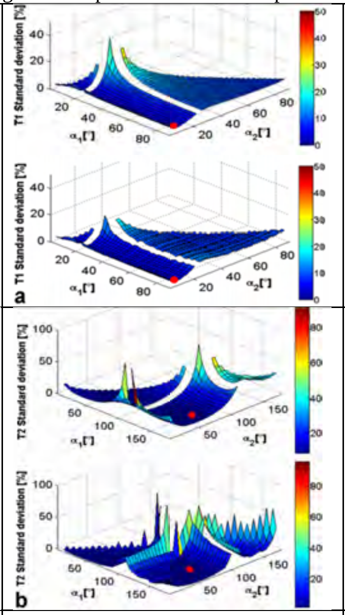

Figure 2: T_1 (a) and T_2 (b) standard deviation [%] from simulation (top) and measurement (bottom) using 3 flip angles and a noise fraction of 5%. Optimum flip angles were found at 7°/23/°87° for T_1 quantification and 60°/103°/151°/ for T_2 quantification.

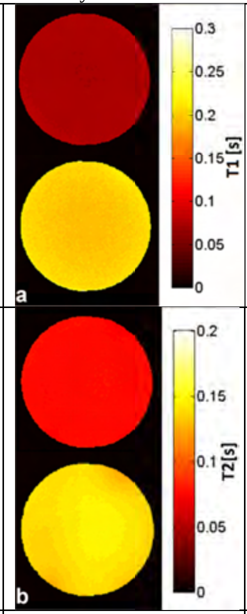

Figure 3: T_1- (a) and T_2 map (b) with conventional 2D-DESPOT1/2 (top, T_1=74±6ms,T_2=76±2ms) and the correction method (bottom,T_1=198±7,T_2=151±17ms)

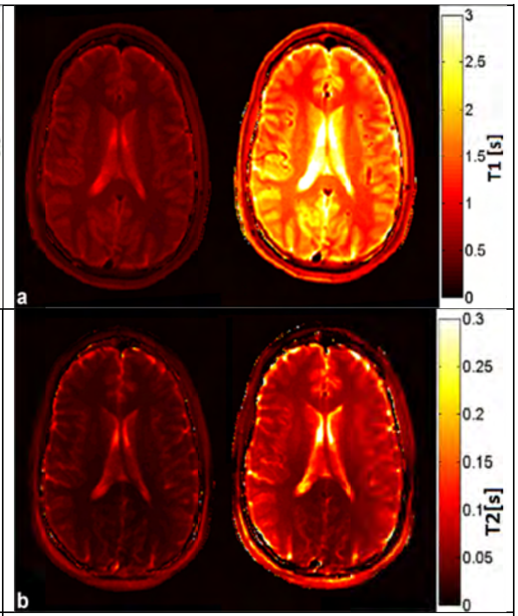

Figure 4: T_1 map (a) and T_2 map (b) using conventional DESPOT1/2 (left) and the corrected method (right). DESPOT1 resulted in T_1 values 537±22ms and 378±17ms, T_2 values of 34±5ms and 22±2ms for gray and white matter, respectively. The corrected method resulted in T_1=1770±90ms/1140±90ms, T_2=86±17ms/63±3ms, which is in good agreement with the literature.

1) Deoni SC et. al., Magn Reson Med 2003;49:515-526., 2) Parker G.J.M et. al., Magn Reson Med 2001;45:838–845, 3) Deimling M. et al. SMRM 1986;p.926, 4) Santoro D et. al., ISMRM 2010;p.4943, 5) Stanisz GJ et. al., Magn Reson Med. 2005 Sep;54(3):507-12.