Rapid 2D variable flip angle (VFA) T1 mapping using sharp slice profiles

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Target audience: Basic MR researchers, imaging scientists, clinical scientists, radiologists, applications specialists interested in parametric T1 mapping.

Purpose: 2D variable flip angle (VFA) T1 mapping has been proposed for fast T1 quantification of the brain [1]. To obtain accurate T1 values, knowledge of the flip angle distribution over the slice is essential. RF pulse imperfections evoke inhomogeneous excitation flip angle distributions in the slice selection direction that inevitably lead to deformations of the slice profile, alter the resulting signal, and hence bear the potential to deem T1 quantification with 2D VFA inaccurate. Sharp and uniform slice excitations could render considerations on complex slice profile corrections obsolete and could afford a direct T1 calculation using gradient echo signal equations. To achieve this goal, impractically long and specific absorption rate (SAR) intensive high bandwidth SINC pulses are conventionally used. In this study, we aim at a reduction of the RF pulse duration using variable rate selective excitation (VERSE, [2]) while maintaining a high slice profile fidelity at the expense of a moderate SAR increase with the ultimate goal of achieving 2D VFA T1 mapping in phantom studies and in vivo.

Materials and Methods: A Matlab implementation of the Shinnar-Le-Roux (SLR) [3] algorithm was used to design a SINC RF pulse (slice thickness=10mm, time-bandwidth-product=34, pulse duration=20ms, bandwidth=1.7kHz, 8 side lobes) to achieve a sharp and uniform spin excitation profile throughout the slice. To shorten the pulse duration and to lower SAR while maintaining the high quality excitation profile, the minimum-time VERSE algorithm was employed. The slice selection gradient strength was used to control the duration of the pulse and to mitigate the characteristic dip in the center of the gradient for improving the off-resonance behavior [4]. A FLASH sequence was modified to accommodate VERSE RF pulses and gradients and to measure slice profiles. Slice profiles were obtained from a cylindrical phantom (T1≈100ms, T2≈80ms). All measurements were conducted on a 3T MR scanner (Verio, Siemens Healthcare, Germany) equipped with a 32 channel Rf head coil with the exception of the slice profile measurements, where the body coil was used for reception. Simulated and measured slice profiles were compared. VFA T1 mapping (voxel size=(2x2x10)mm³; TE=5.4ms, TR=9ms, total acquisition time=5.4s) was conducted on a cylindrical manganese doped water phantom (T1≈500ms, T2≈50ms, d=10cm) at adjusted flip angles (α1=4°, α2=22°, [5]). To correct for B1 non-uniformities, Bloch-Siegert B1 mapping [6] was incorporated (voxel size=(4x4x10)mm³, acquisition time=1.6s). For comparison, an inversion recovery (IR) fast spin echo (SE) technique (voxel size=(2x2x10)mm³; TE=5ms, TR=10s, TI=60/120/240/480/750/1000/3000/5000ms, turbo factor=5, GRAPPA R=2) was used as a reference. 2D VFA T1 mapping (αc=2°, α=13°) was conducted in an axial slice of the brain of a healthy volunteer. Mean T1 values for gray and white matter were derived for both techniques.

Results: The VERSE algorithm shortened the pulse duration from 20ms to 5ms with the excitation profile being identical to the profile achieved with the high bandwidth SINC pulses of 20ms duration. To maintain the RF pulse integral, the four-fold reduction in pulse duration was compensated by an increase in the peak RF amplitude by a factor as low as 2.5 (Figure 1). The simulated slice profile using the SINC pulse matched the slice profile using the VERSE pulse as well as the measured slice profile. Figure 2 shows phantom measurements using the reference IR-SE approach (A) and the proposed B1+ corrected 2D VFA T1 mapping approach (B), and the absolute difference between the two (C). Mean T1 values derived from a ROI covering an axial slice of the phantom were 474±2ms for IR-SE and 469±9ms for 2D VFA T1 mapping. Measurement time was 17.3min for the reference and 7s for 2D VFA. In vivo IR-SE T1 mapping showed T1 values of 1544±188ms in gray matter and 892±66ms in white matter. Measurement time was 17min. 2D VFA T1 mapping showed T1 values of 1596±212ms and 1017±90ms in white matter with a measurement time of 7s.

Discussion: We demonstrated rapid 2D variable flip angle T1 mapping using improved slice profiles at 3T in phantom experiments and in vivo. For this purpose we combined Shinnar-Le-Roux pulses with the VERSE approach. For the proposed approach, no extra corrections for imperfect slice excitation were needed. The standard deviation of T1 in 2D VFA phantom studies was less than 2% of the mean T1 value. VERSE allows for further shortening of the pulse at the expense of stronger slice selection gradients or deterioration of the slice profile fidelity. The low scan time and low computational effort makes the proposed method attractive, since T1 maps are calculated within a few milliseconds. We anticipate extending our explorations into balancing SAR, off-resonance behavior, and slice profile fidelity using VERSE guided numerical RF pulse design [7].

Conclusions: 2D VFA T1 mapping using sharp and uniform excitation profiles is feasible and represents a valuable alternative for rapid T1 mapping of the brain.