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A simple approach to control rms(B1) by pulse length in variable flip angle (VFA) T_1 mapping of human brain

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Synopsis

Controlling the saturation of bound magnetization in variable flip angle (VFA) experiments improves the derived parameter maps. Instead of using special CSMT RF pulses, we kept the rmsB1 constant simply by increasing the RF pulse duration with the square of the flip angle. At 3T, VFA T1 mapping of human brain thus showed better compliance to the Ernst equation than at constant pulse duration or B_1 amplitude, but yielded shorter T_1.

Introduction

Magnetization transfer (MT) effects in mapping T1 or T2/T1 varying the flip angle (VFA) in fast low-angle shot (FLASH) or balanced steady-state free precession (bSSFP) sequences can be stabilized via the average absorption of RF by the “invisible” motionally restricted macromolecular protons[1]. Such “controlled saturation magnetization transfer” (CSMT) can be achieved by complementing the root-mean-square of B1 by adding off-resonance sidebands to the RF pulse[1]. As such RF pulses are not readily available on clinical scanners, we suggest controlling rmsB1 by pulse duration (PL). This is compared to schemes where RF duration or B_{1peak} is hold constant in VFA T_1 mapping of human brain at 3T.

Theory

For a given RF pulse shape and flip angle (FA), the rmsB1 of an RF pulse is proportional to FA^2/PL, which can be kept constant by increasing PL with FA^2. If PL is constant, rmsB1 increases with FA^2. For constant peak B_1, rmsB1 increases with B_{1peak}*FA. Absorption of RF will impose varying partial saturation to the bound pool, which -- compared to 1–*cos*(FA) created by the FA on free pool (Figure 1) -- will lead to MT to or from the free pool that influence the steady state signal[2].

Methods

Measurements were performed on a 3T MAGNETOM Prisma using a 20-channel head-neck coil (Siemens Healthcare, Erlangen, Germany) using a prototype sequence that allowed setting the pulse duration. A healthy male subject (29y) and an agarose phantom (inversion recovery T_1 = 1050ms) were investigated. Sagittal non-selective volumes of 1.25 mm^3 isotropic resolution (240x232x180 mm^3) were acquired at TE/TR=3.78/10ms in 1:30 minutes using partial Fourier and GRAPPA acceleration. The flip angle of a rectangular pulse was varied through 2°, 3°, 4°, 5°, 6°, 8°, 10°, 12° and 15°, while recording the peak voltage. Three cases were investigated:
A) constant rmsB1: A chosen minimum PL of 24us for 2° was increased to 1800us for 15°. The peak voltage was less than 25% of the hardware limit allowing for 4 times higher FA or 2 times shorter PL.
B) constant B1peak: PL was varied from 80us to 600us (kept within the range of A).
C) A constant PL of 400us was chosen, to keep peak voltages within the range of A.
The VFA signals *S*(FA) were plotted as *Y*=*S*(FA)/FA over *X*=*S*(FA)*FA (FA in radian) to enhance signal bias by deviation from a straight line[3]. Signal amplitude and T_1 were obtained by linear regression. The MR system’s B_1^+ mapping based on multi-slice saturation recovery[4] was used to account for local flip angles deviating from the nominal value.

Results and Discussion

At constant rmsB1, the VFA signals followed the Ernst equation, that is, a straight line in Figure 2, better than at constant PL or constant B_{1peak}. This is in line with results using CSMT pulses[1]. Specifically, the latter showed lower signal at higher FA, where the saturation of the bound pool increases.
After each RF pulse, more magnetization will be transferred from the free to the invisible pool, resulting in a lower steady state. In turn, the T_1’s obtained with constant rmsB1 tended to be lower (Figure 3). Even at very long pulse lengths of 1800ms, effects of large B_0 offset were not observed orbito-frontally at 3T.
This proof-of-principle suggests that it can be extended to higher flip angle and use of sinc pulses. Further investigations of incidental MT-effects on T_1 mapping by VFA will be compared to MP-RAGE based isotropic maps of T_1 obtained from fitting the inversion recovery, which has been specifically developed for the purpose of revealing spatial bias (abstract submitted),

Conclusion

By simply increasing the RF duration with the square of the FA, MT effects can be controlled in VFA, reducing systematic signal deviation, but leading to lower T_1 estimates.

Acknowledgements

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References

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Figures

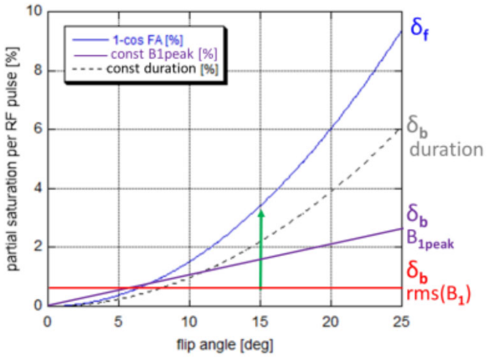

Figure 1: Sketch of the partial saturations of the bound pool imposed by the RF pulse over flip angle, relative to the free pool (blue). The vertical scale is not known and thus arbitrary. Note the different behavior at constant duration (grey) and B_{1peak} (purple). The green arrow at 15° indicates the lower saturation of the bound pool for the three cases, showing that inverse MT toward the free pool is strongest for constant rmsB1 (red).

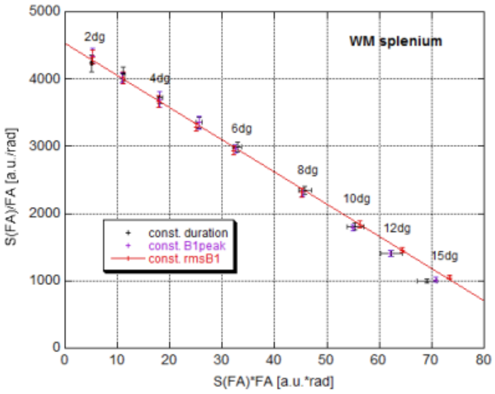

Figure 2: Linear plot of mean VFA signal in a ROI in the genu. Error bars indicate the scaled standard deviation across the ROI. The straight line observed for constant rmsB1 (red) indicates that the signal follows the Ernst equation. The data obtained with constant PL (black) and constant B_{1peak} (purple) deviated with increasing flip angle. The signal differences for a given flip angle (on rays through the origin) follow the differential effects in both pools as sketched in Figure 1.

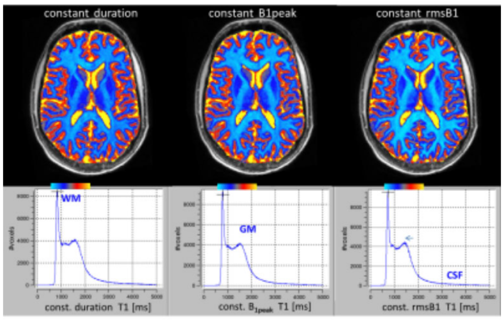

Figure 3: The change in hue of the T_1 maps (pseudocolor scale 600ms to 2200ms) and the whole-brain T_1 histograms show the small, but discernable shift to lower T1 estimates from constant duration (left), constant B_{1peak} (middle), to constant rmsB1 (right).