Optimizing the accuracy of T1 mapping accounting for RF non-linearities and spoiling characteristics in FLASH imaging

Antoine Lutti[1] and Nikolaus Weiskopf[1]
[1]*Wellcome Trust Centre for Neuroimaging, Institute of Neurology, University College London, London, United Kingdom*

Target audience: those interested in quantitative mapping of MR parameters.

Purpose: Quantitative mapping provides powerful insights into tissue microarchitecture (1). Variable flip angle (VFA) methods acquire fast low angle shot (FLASH) images with at least two different nominal excitation flip angles (FA) used to estimate the longitudinal relaxation time T1 (2). Residual transverse coherences in the RF spoiled FLASH signal, spatial inhomogeneities of the transmit field B1 and non-linearities of the RF transmit chain can affect the accuracy and must be corrected (2-5). We address all issues simultaneously and optimize the accuracy of T1 mapping while maintaining a high SNR by carefully optimizing the FLASH protocol.

Methods: *Non-linearities in the RF transmit chain* (NLs) affect the local FA α by (6): α=NLxB1xα_{nom} [1] where α_{nom} is the nominal FA and B1 is the transmit field bias (in p.u.). NLs are voltage dependent (7) and thus not only introduce a general FA bias but also inconsistencies across 2 VFA datasets obtained with different RF transmitter amplitudes. To minimize NLs we kept the RF voltage constant for the 2 VFA acquisitions at a value in the optimal operating range of the scanner. The *B1 bias* was corrected using B1 mapping data also acquired in this optimal range (3). Bias from *imperfect spoiling* was minimized by choosing optimal parameters (FA, RF phase increment and TR) extracted from simulations accounting for diffusion effects (5), while maintaining high SNR. We compared the conventional and optimized protocols (1 and 2) with gold standard IR-TSE R1 maps. Data were acquired on a 3T Siemens TIM Trio operated with RF whole-body transmit and 32-channel receive coils. VFA data was acquired with FLASH acquisitions at a resolution of 1mm^3. Parallel imaging (acceleration factor 2) and partial Fourier (6/8) were used along the phase and partition directions respectively. **Protocol 1.** (TR, α_{nom}) were set to (23.7ms, 6^o) and (18.7ms, 20^o). The change in α_{nom} was achieved by increasing the RF voltage from 50V to 166V. The RF phase increment ϕ was 50^o. The acquisition time was ~12min. **Protocol 2.** (TR, α_{nom}) were set to (24.5ms, 6^o) and (24.5ms, 21^o). The change in α_{nom} was achieved by increasing the RF pulse duration from 40µs to 140µs (with constant amplitude ~250V). ϕ was 137^o. The acquisition time was 14min. **B1 mapping.** A B1 map was used to correct the effects of RF inhomogeneities (2, 3). Spin-echo/stimulated-echo data were acquired for nominal FAs ranging from 230^o/115^o to 130^o/65^o in steps of 10^o/5^o (constant RF amplitude ~350V) (3). The acquisition time was 3mins. **Reference IR-TSE.** A reference T1 map was calculated from inversion recovery data. TI was set to [3000, 2000, 1350, 950, 650, 450, 300, 200] ms and TR was 6s. A single slice with an in-plane resolution of 1.25mm and thickness of 5mm was acquired (~12min).

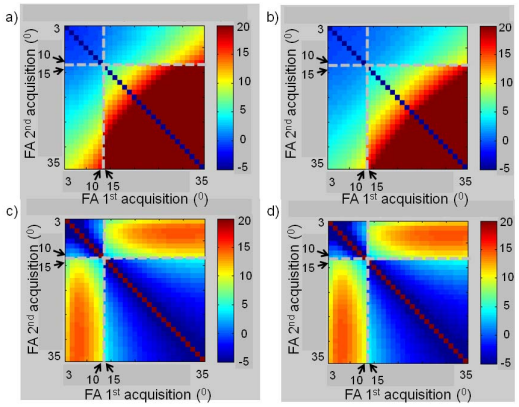

Figure 1. Percent R1 bias as a function of the nominal FA of protocols 1 and 2 with ϕ=50^0 (a) and 137^0 (b). SNR in the R1 maps as a function of the nominal FA of protocols 1 and 2 with ϕ=50^0 (a) and 137^0 (b). The T1/T2 value of white matter at 3T was used to obtain these simulation results.

Results Fig. 1 shows that the T1 bias is minimized with ϕ=137^o compared to the conventional ϕ=50^o at the same SNR level. Fig. 2 represents R1 (=1/T1) maps obtained from protocols 1 (a) and 2 (b) and the reference IR-TSE method (c). The diagonal pattern in (a) resembles that of the B1 map (d), illustrating the inconsistencies between the 2 runs of protocol 1 due to the variable NLs (see eq [1]). This is not visible for protocol 2 where the same RF voltage is used. The R1 bias of protocols 1/2 were (3.8, 3.9, 4, 8.6, 2.4)/(4.8, 1.1, 0.5, 0, 2.9)% compared to the reference values in the genu, splenium, frontal white matter, left and right caudate respectively. They were ~40% smaller for protocol 2 as predicted in Fig. 1.

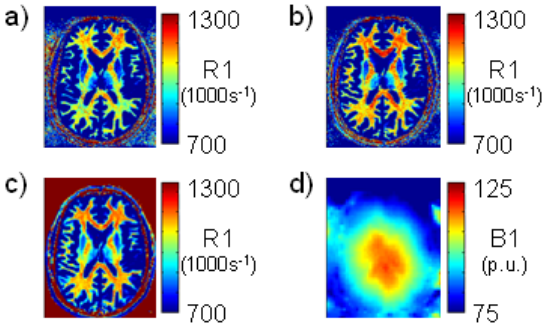

Figure 2. R1 maps obtained using the FLASH protocols 1 (a) and 2 (b) and the reference IR TSE method (c). B1 map used for flip angle correction of the R1 maps (d).

Discussion and Conclusion: We introduced an optimized VFA method for quantitative T1 mapping. The minimization of imperfect spoiling, RF non-linearity and B1 inhomogeneity effects led to significant improvements in the accuracy, which is necessary for advanced applications such as mapping of myeloarchitecture (1).

References: (1) Sereno MI et al. Cereb Cortex 2012. (2) Helms G et al. MRMed 2008. (3) Lutti A et al. PLoS One 2012. (4) Preibisch C & Deichmann R MRM 2009. (5) Yarnykh VL.MRM 2010. (6) Venkatesan R et al. MRM 1998. (7) Levesque IR et al. ISMRM 2011. **Acknowledgments:** This work was funded by the Wellcome Trust.